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TREATMENT AND ULTIMATE DISPOSAL OF CATTLE FEEDLOT
WASTES

Harry L. Manges, et al

Kansas State University

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TREATMENT AND ULTIMATE DISPOSAL OF
CATTLE FEEDLOT WASTES

By

Harry L. Manges
Ralph I. Lipper
Larry S. Murphy
William L. Powers
Lawrence A. Schmid
Kansas State University
Manhattan, Kansas 66506

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Project Officer

David M. Farmer
Robert S. Kerr Environmental Research Laboratory
National Environmental Research Center
P. O. Box 1198
Ada, Oklahoma 74820

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ABSTRACT

A study was conducted to determine the characteristics of beef feedlot wastes, both runoff and manure, and the optimum application rate of these wastes to land. The project was located at a commercial beef feedlot in southcentral Kansas.

Characteristics of beef feedlot wastes varied widely with season.

Near maximum corn forage yields, without excessive accumulation of salt in the soil, were obtained from waste application rates necessary to meet nitrogen fertilizer recommendations. At these waste application rates, basic intake rate of water into the soil was increased. Net income from irrigated corn production was sufficient to make application of feedlot manure with disposal as the main objective unprofitable.

Land application rates of beef feedlot wastes should be based upon the results of laboratory analyses of wastes from each feedlot. Feedlot wastes should be applied at rates necessary to meet nitrogen fertilizer recommendations. A salt-alkali test should be made annually on the surface soil to monitor changes in soil salinity levels.

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SECTION I

CONCLUSIONS

The Soil Conservation Service runoff equation predicted volume of beef feedlot runoff with sufficient accuracy for the design of runoff handling, storage, and treatment facilities. Concentration of pollutants in feedlot runoff from rainfall varied widely during an individual runoff event and from successive runoff events. Concentration of pollutants in feedlot runoff from snowmelt was about double that in runoff from rainfall.

Quantity of manure and accompanying soil removed during cleaning of feedlot pens was quite variable being as low as one kilogram per animal per day following periods of high biological activity and as high as ten kilograms per animal per day following prolonged wet periods. In general, concentration of volatile solids, nitrogen, and phosphorus increased as quantity of manure removed per animal per day decreased. Manure collected from a concrete surface had about twice the moisture content of that collected from a dirt surface, along with a higher concentration of volatile solids, nitrogen, and phosphorus. There was no appreciable change in the characteristics of manure during storage in an undisturbed, compacted stockpile.

Storage of feedlot runoff resulted in apparent chemical oxygen demand removal of about 65 percent. Even with this removal, the liquid was far from a quality suitable for direct discharge to a watercourse.

At the end of four years, maximum corn forage yields were obtained from annual feedlot runoff applications of 29 centimeters. Electrical conductivity of extracts from saturated pastes of surface soil increased linearly with application rates of feedlot runoff. Significant quantities of nitrate-nitrogen accumulated in soil receiving annual feedlot runoff applications of 22 centimeters and greater.

Annual feedlot manure application rates of 29 to 68 dry metric tons per hectare gave near maximum corn forage yields without excessive accumulation of salt in the soil. Positive effects on corn forage yields remained four years after a one-time application of up to 450 dry metric tons per hectare of feedlot manure. In some cases, concentrations of nitrate-nitrogen in corn forage grown on land receiving more than 40

dry metric tons per hectare per year of feedlot manure reached levels at which toxicity can occur if the forage is ingested by animals.

Applications of feedlot wastes did not appreciably change the pH of the neutral to alkaline soil studied. Soil availability of iron, zinc, and manganese, as measured by Diethylene Triamine Penta Acetic Acid extraction, was increased by applications of feedlot runoff and feedlot manure. Corn forage concentrations of zinc and manganese were enhanced by yearly applications of feedlot manure while only the concentrations of manganese were enhanced by yearly applications of feedlot runoff.

Nitrogen balance calculations for plots receiving yearly applications of feedlot manure showed large amounts of nitrogen were not accountable by soil, plant, and manure analyses. Atmospheric and other soil analyses suggested that nitrogen loss occurred from denitrification reactions.

In general, concentrations of chemical oxygen demand, nitrogen, and phosphorus in runoff water from land receiving annual applications of beef feedlot manure increased with increasing feedlot manure application rates and were higher from rainfall runoff than from irrigation runoff. However, five day biochemical oxygen demand was consistently below 10 milligrams per liter in irrigation and rainfall runoff indicating the soil had assimilated the load applied in the manure.

After four annual applications of feedlot manure, the basic intake rate of water into the soil increased as manure application rates increased up to 269 metric tons dry manure per hectare per year and decreased as annual manure application rates continued to increase.

Annual applications of feedlot runoff at rates sufficient for maximum irrigated corn forage yields were the most profitable. Net income from irrigated corn production was sufficient to make application of feedlot manure with disposal as the main objective unprofitable. Although annual applications of feedlot manure increased irrigated corn forage yields, the net return was not sufficient to pay for applying the manure. Large, first-year applications with no manure added in the four subsequent years appeared to be profitable.

SECTION II

RECOMMENDATIONS

Feedlot waste treatment and ultimate disposal can be accomplished by land application with minimal pollution of the environment. The following recommendations are based upon the results of this study.

TREATMENT AND ULTIMATE DISPOSAL OF WASTES

As characteristics of feedlot wastes vary widely, land application rates should be based upon laboratory analyses of wastes from individual feedlots.

Apply feedlot runoff at a rate which will meet the nitrogen fertilizer recommendations for the area. Determine area of land needed for feedlot runoff disposal by the Soil Conservation Service runoff equation using historical rainfall records.

The first year feedlot manure is applied to land, apply at twice the rate necessary to meet nitrogen fertilizer recommendations. Apply at the rate needed to meet nitrogen requirements in subsequent years. Single applications of manure sufficient to meet nitrogen requirements for up to four years may be made with no manure applied in the intervening years.

Collect soil samples annually from the surface six inches and the root zone of the crop and have them analyzed for salt-alkali and nitrate-nitrogen, respectively. If the salinity or nitrate-nitrogen level becomes excessive, adjustments must be made in feedlot waste application rates.

Analyze forages grown on soils following the application of greater than 30 metric tons per hectare of manure for nitrate-nitrogen to insure they will not be toxic to animal health.

RESEARCH NEEDS

Long-term studies are needed to determine the effects of feedlot waste application rates to land on characteristics of the soil, percolating soil water, surface runoff water, and crops grown. These studies

should be conducted on different soil types and under the range of climatic conditions found in the cattle feeding areas.

Obviously, long-term studies cannot be completed in time to provide inputs into the planning and construction of feedlot waste disposal systems started in the near future. The objective of the above recommendation can be met by monitoring changes which occur under the best designed feedlot waste management systems and effecting changes in the system's operation as needed to provide for a viable waste treatment and disposal program.

A large, first-year application of feedlot manure followed by no manure in the subsequent three years gave most profitable corn forage yields in this study. Studies are needed comparing annual manure applications with a large first year application followed by smaller annual applications and large applications at varying time intervals. Selection of the optimum waste application rate should be based upon economics and the potential for pollution of the environment.

Additional research is needed to determine the effects of feedlot waste application rates and tillage practices on the quality of runoff waters from irrigation and precipitation.

SECTION III

INTRODUCTION

BACKGROUND

The trend in the beef industry is towards feeding cattle in large capacity feedlots. As animals are concentrated in a small area, the problem of disposing of their wastes is magnified.

Wastes from beef feedlots are in two forms, liquid and solid. Liquids are the result of stormwater runoff from the feedlot surface. The solids consist of manure and accompanying soil removed from the pens during cleaning.

Land disposal of animal wastes may lead to pollution of land, of stormwater runoff from the disposal site, and of the underlying ground water. The long-term effects of land disposal of material containing small amounts of toxic metals such as are in animal wastes has not been evaluated (Gatehouse¹). Neither has the potential for pollution of runoff from land used for the disposal of animal wastes been measured. Large concentrations of nitrate-nitrogen, apparently from animal sources, have been detected in the soils and shallow aquifers underlying some farmstead areas of northern Missouri (Smith²). These same problems may occur on land used for disposal of feedlot wastes.

Pollution Potential

Miner *et al.*³ found that feedlot runoff is a concentrated organic waste high in nitrogenous compounds. High concentrations of total coliforms, fecal coliforms, and fecal streptococci were measured. Smith and Miner⁴ reported four severe pollution incidents resulting in extensive fish kills below commercial feedlots in Kansas. Septic conditions, high biochemical oxygen demand (BOD) and ammonia concentrations, and high bacterial counts were recorded at the time of observed fish kills which was immediately following runoff-producing rainfall.

Large volumes of manure are generated in cattle feedlots. According to the review of literature prepared by Loehr⁵, a 408 kilogram (kg) steer will generate 4.08 kg of dry manure per day. Manure presents no serious water pollution threat until it is washed away or removed

in cleaning operations. The water pollution problem is associated with disposal of the manure.

Treatment

There are several ways to dispose of feedlot wastes without pollution. All the techniques fall into one or a combination of three categories; i.e., chemical, biological, and physical. Chemical treatments appear to offer less promise than the others for the present due to their high costs. Controlled biological processes suffer due to the intermittent nature of runoff which comes only with precipitation. Biological treatment systems function best when the waste loading rate is uniform and continuous. Continuous flow of waste could be accomplished only with flow equalization ponds which would add to the expense of the waste handling system. Within the area of physical treatment is any technique which involves primarily manipulation of the waste with ultimate disposal as the goal. Almost without exception, any method for handling feedlot waste will require ultimate disposal of the residue.

Loehr⁵ concluded that, at present, there is no profitable method of livestock manure utilization and it is unlikely that one will be developed. As a result, the feedlot industry must accept the method of waste disposal that will prevent pollution at the least cost. The physical treatment technique appears to be the least expensive for complete disposal of feedlot wastes. Therefore, emphasis in this study is on the detention of runoff in storage lagoons with disposal of the runoff and manure onto agricultural land.

Land Disposal

Land disposal was the earliest organized method of waste treatment (Schraufnagel⁶). Sewage from the city of Berlin, Germany, was being applied to 56,000 acres in 1934 (Weise⁷). According to Schraufnagel⁶ sewage farming was still being practiced in 1962 by some large cities including Paris, Berlin, and Melbourne. Gray⁸ reported successful irrigation with effluent from the sewage treatment plant at Lubbock, Texas. In general, irrigation with sewage effluent has increased crop yields (Henry *et al.*,⁹ Henkelekian,¹⁰ Day *et al.*¹¹).

Liquid manure disposal onto land is now being accepted by certain farm operators (Wolf,¹² McKee¹³). Care must be taken so that the soil used as the disposal medium doesn't become polluted. Characterization of feedlot runoff has shown it to vary widely in chemical composition and, generally, to be high in total salt content (Miner *et al.*,¹⁴ Clark and Stewart,¹⁵ Gilbertson *et al.*,¹⁶ McCalla *et al.*,¹⁷ Satterwhite and Gilbertson,¹⁸ Swanson *et al.*¹⁹). After runoff arrives at a lagoon, evaporation can further increase salt concentrations. When such lagoon water is applied to a soil, some of the salts can be used as plant nutrients to increase productivity but excess salts can create soil salinity and dispersion problems.

Only limited data are available on effects of beef feedlot lagoon water on soil properties and plant growth. Travis *et al.*²⁰ found total salts increased by 200% and infiltration declined to zero in soil columns from four Kansas soils after inundation with lagoon water with an electrical conductivity (EC) of 13.4 millimhos per centimeter (mmhos/cm). They suggested that the higher proportion of monovalent cations Na^+ , K^+ , and NH_4^+ in such soil could have dispersed colloids and led to the cessation of infiltration.

Satterwhite and Gilbertson¹⁸ found in a one-year field study that sprinkler applications of up to 30.5 centimeter (cm) of lagoon water increased soil N, P, K, S, and Cl. They compared (in a greenhouse) the effects of tap water, water taken from a lagoon in 1969, and water from the same lagoon in 1970 on plant growth. Both lagoon waters increased total salts in the soil more than did tap water. Growth of nine grass species was enhanced by tap water and by the 1970 lagoon water, but was inhibited by the 1969 lagoon water.

The ultimate fate of most of the solid wastes produced in beef feedlots is application to land. The plant nutrient content of this material is variable, but usually contains on a dry weight basis 1.0% to 3.5% N, 0.32% to 0.85% P, and 0.75% to 2.35% K (Mathers and Stewart,²¹ Mathers *et al.*,²² Reddell²³). Competition for this waste as chemical fertilizer supplement or replacement is expected to increase but high transportation costs will still restrict its distribution. When determining land disposal rates, care must be taken to insure unimpaired productivity of the soil, optimal utilization of plant nutrients, and minimal loss of waste components to ground and surface waters. Little agronomic research has dealt specifically with land disposal of beef feedlot manure at the high disposal rates being used on fields close to large feedlots.

Herron and Erhart²⁴ found that beef feedlot manure increased yields of sorghum forage at application rates of 17.5 and 35.0 dry metric tons per hectare (MT/ha.) on an irrigated calcareous soil compared to plots that received no treatment and that residual effects on yields were present four years after the single manure applications. Approximately 70% of the N contained in the manure had become plant available in four years.

Workers in Texas have conducted several studies on the agronomic aspects of land disposal of beef feedlot manure. Mathers and Stewart²¹ (in the laboratory) mixed manure (3.25% N and 32% C) with a silty clay loam soil at six rates of from 0% to 20% manure. From 45% to 52% of the added C was evolved as $\text{CO}_2\text{-C}$, and from 46% to 50% of the added N was converted to $\text{NH}_3\text{-N}$, $\text{NH}_4^+\text{-N}$ and $\text{NO}_2\text{-N}$ during 90 days of incubation. Total mineralization was thus similar for both N and C. Work with similar manure-soil mixtures in a greenhouse experiment showed that after two croppings, the value of 2.4 kg of N from manure was equivalent to 1.0 kg of N from ammonium nitrate for the nutritional requirements of grain sorghum, expressed as yield. Mathers *et al.*²² found in a three-year field study that feedlot manure applications of 269 and 538 metric tons per hectare

per year (MT/ha./yr) lowered grain sorghum yields and greater than 112 MT/ha./yr reduced corn forage yields. The yield depressions were attributed to salt buildup in soil. No grain sorghum yield differences were found between manure application rates of 22.4, 67.3 or 135 MT/ha./yr. Nitrate-N accumulated in the surface 2 meters (m) of soils receiving 112 and 224 MT/ha./yr and was increased in sorghum plants to levels not considered toxic at manure rates of from 22.4 to 269 MT/ha./yr. Surface soil organic matter and soluble salts were increased by disposal rates of from 22.4 to 269 MT/ha./yr. Reddell and coworkers^{23,25} at three locations applied beef manure in single applications of 673, 1350, and 2020 wet MT/ha. (49%, 52%, and 36% dry matter at the three locations) to soil and covered the manure by deep plowing (91 cm deep). Yields of corn and sorghum forage for two years after manure applications were made increased over the control plot (no treatment), with maximum yields occurring at the 673 MT/ha. rate. The NO₃-N content of both forages was increased to potentially toxic levels at one location during one of the two growing seasons. At one location, eight treatments of 22.4 to 2020 wet MT/ha. (64% dry matter) were applied and yields of corn forage and sorghum grain were measured. Maximum corn forage yields were realized at the 22.4 wet MT/ha. rate and steadily decreased at the higher rates. Grain sorghum yields increased to the 336 wet MT/ha. rate and decreased relative to the maximum at higher rates. The depressed growth was again attributed to salt injury.

Micronutrient Relationships

Numerous researchers have found manure to be a source of N (Bunting²⁶, Garner²⁷, Haworth²⁸, Lindsay²⁹, Ridley and Hedlin³⁰), P (Bunting²⁶, Garner²⁷, Haworth²⁸, Ridley and Hedlin³⁰, Abbott and Lingle³¹, Carlson et al.³², Widdowson and Penny³³), and K (Bunting²⁶, Garner²⁷, Haworth²⁸, Widdowson and Penny³³, Austin³⁴, Garner³⁵, Haworth³⁶) for improved soil fertility as reflected in increased crop yields, while others (Bunting²⁶, Haworth²⁸, Austin³⁴, Bishop et al.³⁷, Haworth³⁸, Holliday et al.³⁹) have reported increased yields that couldn't be traced to improved availability of N, P, or K. These unexplained yield increases could be due to improved soil structure (Bunting²⁶, Austin³⁴, Haworth³⁹, Holliday et al.³⁹, Haworth⁴⁰, Salter and Haworth^{41,42,43}, Williams and Cooke⁴⁴) and subsequent positive effects on permeability, waterholding capacity, and soil aeration, or to trace elements contained in the manure. The trace element content of manure and feedlot runoff is variable (McCalla et al.¹⁷, Mathers et al.²², Atkinson et al.⁴⁵, Hensler et al.^{46,47}). Manure has increased or not affected soil pH (Bishop et al.³⁷, Hensler et al.⁴⁷, Atkinson et al.⁴⁸, Barnes et al.⁴⁹, Brage et al.⁵⁰, Thompson⁵¹) which indicates that altered soil pH may be a mechanism by which manure can change the availability of soil nutrients.

A deficiency of Fe in corn grown on a soil deficient in Fe and Zn was partially corrected by applications of poultry manure in a greenhouse study conducted by Miller et al.⁵² while in the same study, a deficiency

of Zn was completely corrected. Carlson *et al.*³² found manure to be a source of Zn in corn grown on a subsoil deficient in Zn, while Meeler and Randhawa⁵³ found manure to depress corn yields and the uptake of Zn. Hensler *et al.*^{46,47} in a greenhouse study, found that dairy manure increased corn tissue concentrations of Zn and Fe on unlimed soil and of Zn and Cu on limed soil, while lowering the Mn concentrations of corn on the unlimed soil. Increased soil pH was suggested as the reason for the depressed Mn content. Recovery from the manure of Fe, Zn, Mn, and Cu generally decreased with increasing manure applications, probably due to relatively lessened yield responses. Increased soil pH was also suggested by Atkinson *et al.*⁴⁸ as the reason for decreased Mn content of ladino clover that had received farmyard manure. Depressed Mn content and unaltered Fe, Zn, and Cu content of vegetable leaves was found by Page⁵⁴. Cow manure increased the exchangeable Cu content of a soil in an incubation study by Gupta⁵⁵.

Denitrification

The fate of the N fraction of animal wastes after land application has both economic and environmental importance. If the waste is being used as a substitute for chemical fertilizers, then emphasis should be on maximum utilization of the added N by the crop being grown. If land applications are to provide a means of waste disposal, then there should be concern about potential contamination of groundwater by N which is frequently applied in excess of that removed by the crop. Loss to the atmosphere of nitrogenous gases through denitrification reactions in soil is a mechanism that lowers the amount of plant-available N and, at the same time, decreases the potential for groundwater contamination. Recognition of these facts has prompted scientists to investigate factors affecting denitrification in soil after waste applications and to measure the resultant N losses.

Broadbent and Clark⁵⁶ have reviewed the conditions necessary for or conducive to denitrification in soil: reducing or anaerobic conditions, source of easily oxidizable C, basic pH, presence of nitrate-N, relatively high temperature, and a denitrifying microbial population. Applications of animal wastes to soil help to promote several of these conditions. The waste organic matter fraction provides a C source, and stimulated microbial respiration of this organic matter helps create anaerobic conditions by removing O₂ from the soil atmosphere. Irrigation can further reduce O₂ levels by restricting gas exchange with the above-ground atmosphere. Mineralization of organic N into NO₃-N provides the denitrification substrate, and some wastes have been shown to increase soil pH (Hensler *et al.*⁴⁷).

Several researchers have measured N losses in soil after animal waste applications. Olsen *et al.*⁵⁷ found in a greenhouse study that 20% to 76% of the N added to soil by dairy cattle manure was lost through volatilization. Koelliker and Miner⁵⁸ reported an unaccountable N loss of 2,307 kilograms per hectare (kg/ha.) in soil treated with anaerobic

livestock lagoon effluent by a sprinkler system. This loss was attributed to denitrification.

In a greenhouse study, Mathers and Stewart²¹ found that N losses apparently due to denitrification were maximized by small, frequent applications of beef feedlot manure. Larsen and Axley⁵⁹ calculated that up to 831 kg/ha. of N was being lost by denitrification in soil that had received sprinkler applications of poultry processing wastes, and Erickson *et al.*⁶⁰ removed 98.8% and 95.8% of the N in liquid swine and dairy waste, respectively, when applied by sprinkler to a layered soil renovation system. Adriano *et al.*⁶¹ estimated that 50% of the excess N added to soils by dairy cattle wastes is either denitrified or becomes a part of the organic N pool.

Water Infiltration

Most manure generated in beef feedlots is applied to cultivated land. Application of manure will alter the soil's composition and thereby change its water intake characteristics.

Cross and Fischbach⁶² conducted a two-year study with maximum manure applications of 582 and 414 metric tons dry matter per hectare the first and second year, respectively, to a Sharpsburg silt loam soil. They reported that the initial intake rate increased as manure application rate increased, the basic intake rate increased with elapsed time from date of application, basic water intake rate decreased as manure application rate increased, and depth of plowing did not appreciably affect basic intake rate. Swader and Stewart⁶³ found that three annual applications of manure at 22, 45 and 112 metric tons per hectare tended to increase the intake rate into the plow layer of a Pullman clay loam soil.

SCOPE

Manure generated in beef feedlots and stormwater runoff are sources of pollution to streams, groundwater, and land. We have postulated that pollution can be minimized by the orderly disposal of feedlot wastes onto cropland. This project was conducted to determine the quantity and properties of wastes generated at a beef feedlot and the optimum waste application rates onto land with a minimum of pollution to land, its stormwater runoff, and the groundwater. Of particular concern was the fate of the large amounts of nitrogen carried in these wastes.

OBJECTIVES

The objectives of the project were:

- a. To characterize stormwater runoff from the feedlot area.
- b. To characterize manure generated in the feedlot.
- c. To determine the effect of storage in an anaerobic lagoon on the quality of feedlot runoff.

- d. To determine the influence of different feedlot runoff loadings on the soil, the soil leachate, stormwater runoff from the treated soil, and corn yields.
- e. To determine the influence of different manure loadings on the soil, the soil leachate, stormwater runoff from the manured soil, removal of nutrient elements from the soil by corn, and corn yields.
- f. To determine the most economical loading of feedlot runoff and manure onto land compatible with pollution control.

SECTION IV

PROJECT FACILITIES

GENERAL

This project was conducted at the Pratt Feedlot, Inc., a 33,000-head commercial beef feedlot located 10 kilometers (km) north of Pratt, Kansas. The feedlot was built on an abandoned World War II air base.

Feedlot Pens

Driveways for delivering feed to feedbunks built along both their sides are located in the center of the concrete runways. Feedlot pens extend away from the feedbunks with access alleys for handling cattle at their lower end. The surface of the pens slopes away from the feedbunks with runoff water carried across the access alleys into drainage channels. The upper 20% to 25% of the pen area is on the side of the concrete runway and the remaining pen area has a dirt surface.

Waste Handling Facilities

Stormwater runoff from the feedlot is directed into storage reservoirs. A sewage pump has been installed in each reservoir. The sewage pumps are interconnected with an underground plastic pipeline which is also connected to an irrigation well. Feedlot runoff and well water can be pumped onto approximately 80 hectares (ha.) of land which has been leveled for surface irrigation. Two tailwater recovery pits are located at the lower end of the irrigated fields to return runoff from irrigation to the storage reservoirs. The waste disposal system has been approved by the Kansas State Department of Health and is licensed as required by Kansas law.

Manure is removed from the feedlot pens after the cattle are sold and before a new group arrives. The manure is windrowed with a motor grader. A paddle scraper then loads the windrowed manure and carries it to a stockpile where it is stored until land is open for disposal. Manure is spread onto cultivated land in the spring before the soil is tilled or in the fall after crops are harvested.

Waste Disposal Plots

Sixty plots were established in 1969 for waste disposal studies. The plots were located approximately 0.8 km from the feedlot pens. Twenty plots, 4 treatments and a control replicated 4 times in a randomized block design, received applications of feedlot runoff. All plots were 9.1 meters (m) wide and contained 12 rows of corn. Two replications were on an odd shaped area of land with plot lengths varying from 60 m to 110 m. The plots in the other 2 replications were 64 m long. Manure was applied to 40 plots, 9 treatments and a control replicated 4 times in a randomized block design. All plots were 9.1 m wide and 64 m long and contained 12 rows of corn.

The predominant soil on the waste disposal study area has been classified as Farnum loam with 2 replications of the runoff disposal plots extending onto Naron fine sandy loam (USDA - Soil Conservation Service⁶⁴). As the original land surface was undulating, considerable areas of subsoil were exposed during leveling for surface irrigation. Laboratory analyses show the surface soil to be a silty clay loam with a cation exchange capacity of 19 milliequivalents (meq) per 100 grams (g) and a pH of 7.0.

Precipitation

The Pratt Feedlot, Inc., is located in Southcentral Kansas where precipitation is quite variable. Table 1 gives monthly precipitation for the period 1969 through 1973 along with monthly normals measured at the National Weather Service station 3 km east of Pratt.

Table 1. PRATT PRECIPITATION^a

Month	Year					Normal
	1969	1970	1971	1972	1973	
	cm	cm	cm	cm	cm	cm
January	T	0.89	1.78	0.63	4.29	1.45
February	4.67	0.28	5.79	T	3.05	2.74
March	5.71	6.73	0.51	0.42	22.02	3.56
April	4.14	6.88	3.65	2.90	8.18	5.13
May	11.00	9.68	6.73	13.41	1.37	8.66
June	7.16	3.73	14.07	9.47	1.19	9.73
July	9.22	2.64	9.52	17.83	15.01	7.34
August	16.46	3.35	0.97	9.78	2.44	7.26
September	15.93	8.61	3.71	5.41	24.03	6.43
October	5.59	5.38	14.00	2.34	13.49	5.74
November	0.08	T	6.65	7.72	1.32	2.16
December	1.42	0.23	1.17	4.27	7.49	2.29
Annual	81.38	48.40	68.46	74.19	103.88	62.49

^aNational Weather Service station 3 km east of Pratt.

SECTION V

RUNOFF CHARACTERIZATION

GENERAL

The volume of feedlot runoff from individual rainfall events must be known for proper sizing of storage reservoirs. Characteristics of the runoff will influence its optimum application rate to cropland. Rainfall-runoff relationships and characteristics of feedlot runoff were determined.

METHODS AND PROCEDURES

Runoff was characterized from two separate areas of the Pratt Feedlot, Inc., which were designated Area 119 and Area 2.

Area 119 consisted of one feedlot pen, 75 m deep and 93 m wide, along with adjacent access areas and covered 0.82 ha. Approximately 18 m across the upper end of the pen adjacent to the feedbunks were surfaced with concrete; the remaining area had a dirt surface. Drainage was diagonally across the pen on about a 1% slope into an anaerobic lagoon.

Runoff from Area 119 was directed through a 0.4572-meter H-flume equipped with a water level recorder and an automatic vacuum sampler. A float device rose in response to flow to activate the water level recorder and sampler. Sampling was controlled by a time clock with a sample drawn every 10 minutes for up to the first four hours of a runoff event.

Area 2 consisted of 25 feedlot pens covering 11.1 ha. Total drainage area was 13.3 ha. including pens, drainage channel to the flow measuring and sampling station, and access areas. All lots were 92 m deep with widths varying from 40 m to 61 m. Approximately 18 m across the upper end of the pens adjacent to the feedbunks were surfaced with concrete; the remaining area had a dirt surface. Lots were mounded along the sides to provide a dry area for the cattle during wet weather. Mounds were 1.2 m above the drainage path which ran down the center of each pen. Lot drainage slopes were 1.3%. Runoff from the individual pens was collected in a drainage ditch with a slope of 0.26 percent and conveyed to a storage reservoir.

Runoff from Area 2 was directed through a 0.762-meter Parshall flume equipped with a water level recorder and an automatic vacuum sampler. Flow was measured and sampled by the same procedure as for Area 119.

Runoff samples were collected from the samplers and refrigerated soon after a runoff event. The samples were packed in ice and transported to Manhattan, Kansas, where they were again refrigerated until laboratory analyses were made. Runoff samples were analyzed for chemical oxygen demand (COD) by acid oxidation according to Standard Methods⁶⁵ for total N by the micro-kjeldahl method, for total P by acid digestion followed with colorimetric procedures, for total solids (TS) by evaporation, for volatile solids (VS) by combustion, for NH_4^+ -N and NO_3^- -N by steam distillation procedures, for EC by a resistance meter, and for Ca, Mg, Na, and K by standard atomic absorption and flame photometric procedures.

Precipitation was measured with a recording rain and snow gauge located adjacent to Area 119. As Area 2 was about 1 km from Area 119, rainfall was also measured with 3 non-recording rain gauges evenly distributed across Area 2.

RESULTS AND DISCUSSION

Volume of Runoff

Depth of rainfall and resulting runoff from individual rainfall events are given in Table 2 for Areas 119 and 2. As the Soil Conservation Service (SCS) runoff equation is used in the design of soil and water conservation structures, its application to feedlots was evaluated.

The SCS runoff equation (SCS National Engineering Handbook⁶⁶) is:

$$Q = \frac{(P - 0.51 S)^2}{P + 2.03 S} \quad (1)$$

where Q = Surface runoff, cm
P = Rainfall, cm
S = Potential maximum retention of water
(interception by vegetation, surface storage, and infiltration into the soil), cm

S is evaluated from the equation:

$$S = \frac{1000}{\text{CN}} - 10 \quad (2)$$

where CN = Runoff curve number

Table 2. RAINFALL AND RUNOFF DATA

Rainfall cm	Runoff cm	5-day antecedent moisture cm	Runoff curve number
Area 119			
1.84	0.31	0.00	88
0.81	0.02	1.83	90
1.93	0.71	2.65	93
1.30	0.73	0.13	97
0.51	0.18	1.42	98
1.22	0.07	0.00	88
2.24	1.47	0.00	97
0.38	0.01	2.24	95
1.63	0.73	0.00	95
1.19	0.25	0.00	93
Mean	-	-	93
Area 2			
1.93	0.30	2.65	87
1.78	0.40	2.11	91
2.79	1.48	0.00	94
0.38	0.00	2.24	94
1.35	0.23	0.00	91
4.06	1.66	0.00	88
1.24	0.29	0.00	93
3.56	2.22	1.19	94
0.30	0.09	4.37	99
Mean	-	-	92

The runoff curve number for each runoff event was determined by substituting measured rainfall and runoff into Equations 1 and 2. Table 2 gives calculated runoff curve numbers. Mean runoff curve numbers were 93 for Area 119 whose surface was one-fourth concrete and three-fourths dirt with an area of 0.82 ha. and 92 for Area 2 whose surface was one-fifth concrete and four-fifths dirt with an area of 13.3 ha. The slightly lower runoff curve number and lower volume of runoff from Area 2 can be attributed to increased infiltration in the longer drainageways from the larger drainage area.

Miner *et al.*¹⁴ reported runoff curve numbers of 91 and 94 for feedlot surfaces of dirt and concrete, respectively. From their work, the weighted runoff curve number for Areas 119 and 2 is 92, which was the mean calculated for Area 2.

Antecedent moisture condition (rainfall during the preceding five days) is normally considered when predicting runoff by the SCS method. Average moisture conditions were assumed for the above analysis. A plot of predicted runoff using mean runoff curve numbers versus measured runoff indicated a low degree of correlation, but the scatter of points indicated the errors were random. Table 2 gives antecedent moisture conditions for each runoff event. When antecedent moisture conditions were considered, a plot of predicted runoff using mean runoff curve numbers indicated a higher degree of correlation, but runoff was consistently underpredicted and the errors were not random. These results on the effects of considering antecedent moisture conditions when evaluating runoff curve numbers are in agreement with the SCS National Engineering Handbook.⁶⁶

The influence of antecedent moisture conditions on runoff from a feedlot surface is difficult to correlate with antecedent moisture conditions for cropland or grassland because:

- a. In addition to rainfall, there is water from daily animal excretion.
- b. Movement of the animals continually stirs the surface and evaporation is increased.
- c. Infiltration into the manure pack of a dry feedlot surface (low antecedent moisture condition) is high due to its high organic matter content.
- d. Infiltration into the manure pack under average and high antecedent moisture conditions is very low.
- e. Movement of water through the manure pack to the underlying soil is minimal.
- f. Surface storage is high under average antecedent moisture conditions, due to the many indentations formed by the hoofs of the cattle.

Based upon the data collected and the above considerations, we have concluded that runoff curve numbers of 91 and 94 for feedlot surfaces of dirt and concrete, respectively, are appropriate for both low and average antecedent moisture conditions. For high antecedent moisture conditions, runoff curve numbers of 97 and 98 are applicable for dirt and concrete surfaces, respectively. Where runoff flows directly off a small feedlot into an adjacent storage reservoir, runoff curve numbers of 92 and 95 are appropriate for dirt and concrete surfaces, respectively, for low and average antecedent moisture conditions and a runoff curve number of 98 is applicable for all surfaces for high antecedent moisture conditions.

Quality of Rainfall Runoff

Table 3 gives the range, mean, and standard deviation of measured pollutional parameters for rainfall runoff for Areas 119 and 2. Concentration of pollutional parameters varied widely during individual runoff events and between runoff events as evidenced by the large

Table 3. CHARACTERISTICS OF RAINFALL RUNOFF

Parameter	Units	Range	Mean	Standard deviation	Number of observation
Area 119					
COD	mg/l	16,100-861	7,596	3,255	72
N	mg/l	1,580-165	675	364	55
P	mg/l	242-9	79	42	56
TS	mg/l	19,252-214	8,442	5,190	48
VS	%	60-12	45	12	48
VS	mg/l	9,552-36	3,888	2,680	48
NH ₄ ⁺ - N	mg/l	580-0	159	112	81
NO ₃ ⁻ - N	mg/l	48-0	10	18	81
Na	mg/l	2,970-31	560	551	81
K	mg/l	2,990-29	796	586	81
Ca	mg/l	402-31	181	83	81
Mg	mg/l	183-35	98	29	81
Ec	mmhos/cm	15-1	7	3	78
Area 2					
COD	mg/l	14,309-1,514	6,111	2,631	85
N	mg/l	962-85	494	211	51
P	mg/l	482-19	87	89	86
TS	mg/l	17,669-2,971	7,528	2,622	63
VS	%	70-38	51	7	63
VS	mg/l	11,437-1,429	3,891	1,627	63
NH ₄ ⁺ - N	mg/l	285-14	141	57	99
NO ₃ ⁻ - N	mg/l	45-0	5	6	99
Na	mg/l	735-67	334	132	99
K	mg/l	2,150-134	851	480	99
Ca	mg/l	1,040-40	187	124	99
Mg	mg/l	228-22	86	40	99
Ec	mmhos/cm	11-1	5	2	99

standard deviations from the means. There was no significant difference in quality of runoff from the two areas.

Concentration of pollutional parameters decreased as the runoff hydrograph was rising and increased as it was falling. This trend can be attributed to increasing solubility of material on the feedlot surface as rainfall continues. When rainfall ends and runoff subsides, the liquid flowing off is that water which was in contact with the manure pack and, consequently, of highest pollutant concentration. No correlation was found between pollutant concentrations and runoff rate because of the variability of runoff quality with time, as well as runoff rate during a runoff event and differences in pollutant concentrations from successive storms.

COD of rainfall runoff, expressed in milligrams per liter (mg/l), was found to be correlated with climatological parameters rather than flow rate as follows:

$$\text{COD} = 65,313 + 18.37 t - 428 M_5 - 1,033 T_g + 4.387 W_5; r = 0.79 \quad (3)$$

where COD = Chemical oxygen demand, mg/l
 t = Time since runoff began, minutes
 M₅ = 5 day antecedent moisture, cm
 T_g = Mean daily ground temperature, °C
 W₅ = Total wind travel for 5 days prior to the runoff event, km
 r = Correlation coefficient

Ground temperature data were taken from a depth of 10.2 cm at the Hutchinson Experimental Field, 41 miles to the northeast and wind data were taken from Kanopolis Dam, 78 miles to the northeast of Pratt. These were the closest stations where soil temperatures and wind travel were recorded.

Approximately 40% of the variation in COD concentration could be attributed to changes in ground temperature, with COD varying inversely with temperature. This was expected as biological activity about doubles with each increase in temperature of 10° C. With warm ground temperatures much of the organic material, as indicated by COD values, will be stabilized on the feedlot surface and not be carried away by subsequent runoff.

N, P, TS, and VS concentrations in mg/l were correlated with COD by the following relationships:

$$N = 0.091 \text{ COD} - 137; r = 0.88 \quad (4)$$

$$P = 0.036 \text{ COD} - 153; r = 0.64 \quad (5)$$

$$TS = 2.74 \text{ COD} - 11,120; r = 0.52 \quad (6)$$

$$VS = 1.08 \text{ COD} - 2,132; r = 0.84 \quad (7)$$

N and VS were highly correlated with COD as should be expected because all three parameters are indirectly a measure of organic strength. Although statistically significant at the 0.01 level, P and TS were not so highly correlated with COD.

Natural occurrences in 1970 allowed for evaluation of the effects of pen cleanliness upon runoff. Pen 119, which was the watershed for Area 119, was cleaned on June 8 and stocked with cattle on June 10. Rainfall of about 1.3 cm fell 11 days prior to cleaning of the pen and 3 days after pen cleaning. Table 4 gives concentration of pollutional parameters and total quantity of runoff. The only significant differences in quality were in concentrations of TS and VS. Total solids were higher, statistically significant at the 0.05 level, in runoff from the cleaned pen because of the higher volume of runoff due to reduced surface storage. Volatile solids were higher, statistically significant at the 0.001 level, in runoff from the uncleaned pen because of the larger amount of organic matter present.

Table 4. EFFECTS OF PEN CLEANLINESS UPON RUNOFF

Condition	Total runoff m ³	COD mg/l	Mean Concentrations			VS %
			N mg/l	P mg/l	TS mg/l	
Before Cleaning	58.8	5,665	364	71	7,904	53
After Cleaning	74.1	4,315	396	52	10,895	27

Quality of Snowmelt Runoff

Table 5 gives the range, mean, and standard deviation of measured pollutional parameters for snowmelt runoff from Areas 119 and 2. Concentrations of pollutants were about double those measured from rainfall runoff.

Solids Accumulation Within a Runoff Storage Lagoon

In September of 1971 following a dry summer, the liquid from the lagoon below Area 119 evaporated, leaving the solids behind. A topographic map of the lagoon had been prepared following its construction. The area was resurveyed in order to determine the net accumulation of solids. The material remaining could best be described as having the appearance

Table 5. CHARACTERISTICS OF SNOWMELT RUNOFF

Parameter	Units	Range	Mean	Standard Deviation	Number of Observations
Area 119					
COD	mg/l	21,700-11,520	16,060	3,566	9
N	mg/l	1,860-1,080	1,450	379	6
P	mg/l	270-122	171	55	6
TS	mg/l	21,530-10,744	15,097	4,679	6
VS	%	63-61	62	1	6
VS	mg/l	13,628-6,586	9,460	3,026	6
NH ₄ ⁺ - N	mg/l	1,370-446	674	247	16
NO ₃ ⁻ - N	mg/l	30-10	18	6	16
Na	mg/l	1,130-369	584	208	16
K	mg/l	3,300-1,080	1,699	561	16
Ca	mg/l	666-202	350	129	16
Mg	mg/l	222-79	122	44	16
Ec	mmhos/cm	22-9	12	4	15
Area 2					
COD	mg/l	35,764-7,299	13,767	8,087	23
N	mg/l	2,337-590	1,033	617	8
P	mg/l	459-65	209	171	12
TS	mg/l	36,684-9,282	19,308	11,425	10
VS	%	65-50	57	6	10
VS	mg/l	23,551-5,253	11,620	7,924	10

of swamp mud. It was nearly odorless and appeared to be well stabilized. Samples were taken and combined in order to arrive at an average characteristic for this material.

The volume of accumulated solids was 143 m³. The characteristics were as follows: moisture (dry basis) - 73%, VS - 19.1%, total N - 0.093%, and total P - 0.094%. As solids had accumulated for two years from the 0.8-ha. area and stocking rate was 250 head, solids accumulation was 0.29 m³ per year per head of feedlot capacity. This figure will be highly variable depending upon feedlot slope, soil conditions, management practices, and length and gradient of the channel carrying runoff from the feedlot pens to the storage lagoon as well as frequency, quantity, and intensity of precipitation.

SECTION VI

MANURE CHARACTERIZATION

GENERAL

Large quantities of manure are generated in beef feedlots. Land area required for disposal depends on quantity of manure and its characteristics. When the feedlot pens were cleaned, the quantity and characteristics of the manure were determined.

METHODS AND PROCEDURES

Usually, feedlot pens are cleaned prior to the arrival of each new group of cattle. During cleaning operations, 5% to 20% of the loads selected at random were weighed and grab samples taken for laboratory analyses. The manure samples were analyzed for N and P by steam distillation and colorimetric procedures after a sulfuric acid digestion, for VS by combustion, and for moisture content by drying at 105° C for 48 hours.

RESULTS AND DISCUSSION

Table 6 gives quantity and quality of dry manure removed during cleaning operations along with a history of the pens since they were last cleaned. Quantity of dry manure removed during cleaning varied from 1.18 to 10.25 kg per animal per day depending on the season of the year. The smaller quantity removed during July, August, and September reflects losses due to biological action and wind and water erosion during the feeding period while the larger quantities with a lower percentage of VS removed during the remainder of the year reflect increased dirt content when the feedlot surface remained damp to wet. Comparison of the quantities of manure removed on July 27 and 28, 1970, shows that larger animals defecate larger quantities.

The upper 18 m of the pen, adjacent to the feedbunks, was paved with concrete. The remainder of the pen had a dirt surface. Table 7 presents some results of manure samples collected from the dirt portion of the lot and the concrete portion at two different times of the year, July and November. The manure from the concrete portion had a much higher moisture content, more than double that of the dirt portion. This can be attributed to the lack of drainage and to more defecation

Table 6. CHARACTERISTICS OF MANURE REMOVED FROM PENS AND HISTORY SINCE PREVIOUS CLEANING

Date Cleaned	Pen size		Cattle data			Per animal day		Dry manure	
	width	depth	per pen, #	weight in, kg	weight out, kg	dry manure, kg	volatile solids, kg	N, %	P, %
08/21/69 ^a	45.7	91.7	188	254	479	4.67	-	1.20	0.55
10/07/69 ^a	91.4	74.4	297	320	477	-	-	-	-
11/14/69	45.7	91.7	298	291	399	5.99	-	1.21	-
01/12/70	45.7	91.7	209	291	500	3.54	-	1.08	-
02/16/70	45.7	74.4	173	278	485	6.17	-	-	-
02/25/70	45.7	74.4	147	348	534	6.49	-	-	-
03/27/70	45.7	74.4	143	284	495	5.40	2.10	-	-
06/08/70	91.4	74.4	126	336	536	4.40	-	-	-
07/27/70	45.7	74.4	251	316	490	4.85	2.41	1.96	2.34
07/28/70	45.7	74.4	134	305	519	1.72	0.94	4.43	0.89
09/21/70	61.0	76.2	119	371	544	2.36	1.00	3.85	0.76
11/11/70	91.4	74.4	223	299	503	1.18	0.62	-	-
12/02/70	30.5	74.4	299	304	509	3.99	1.79	2.92	0.80
12/22/70	45.7	74.4	96	335	537	5.99	2.05	2.83	0.66
05/06/71	91.4	74.4	124	318	523	6.76	3.06	3.58	0.79
05/07/71	91.4	74.4	288	324	507	10.25	2.79	0.83	0.52
05/18/71	91.7	45.7	259	341	530	7.94	2.29	1.57	0.52
			176	305	528	7.76	2.23	0.84	0.53

^a Pens not cleaned between groups of cattle.

Table 7. MANURE QUALITY FROM PENS AND STOCKPILE

Date	Sample location	Moisture % of dry wt.	Kjeldahl-N % of dry wt.	Total-P % of dry wt.	Volatile solids % of dry wt.
Pen 119					
7/13/70	Dirt	10.2	2.00	0.50	56.2
	Concrete	23.4	4.37	1.30	68.8
11/04/70	Dirt	20.0	2.76	0.70	35.8
	Concrete	47.8	6.10	1.47	64.8
Stockpile ^a					
7/08/70 11/11/70	Composite	--	3.95	0.74	31.7
	Top layer	46.3	3.05	0.64	31.7
	0.3 m deep	42.7	4.00	0.80	32.9
	0.6 m deep	54.7	3.22	0.80	35.2
	0.9 m deep	52.7	3.88	0.86	37.8
	1.2 m deep	51.8	3.71	0.71	33.0
	1.5 m deep	32.7	2.78	1.15	37.3
Stockpile Application to Field Plots					
Fall 1969 ^b	--	--	1.04	0.39	26.7
Fall 1970 ^c	--	--	3.12	0.71	42.2
Fall 1971 ^c	--	--	1.02	0.36	21.1

^a Stockpile was 1.8 m deep.^b Average of 28 samples.^c Average of 24 samples.

because it is at the feeding area. This fresher material at the bunk also contained more N and P and had a higher VS content, indicating that it was of higher organic strength. The sample taken from the dirt area of the lot contained an unknown amount of soil worked into the manure pack by the hoofs of the cattle.

The manure stockpile was sampled during 1970. These results are presented in Table 7. Samples were taken while the manure was being removed from the stockpile in November, 1970, and analyzed in the laboratory. There appeared to be no appreciable difference in manure quality with depth especially considering the variations that would be expected from the lots themselves. Also, there was no significant difference in quality between sampling dates of July 8 and November 11, 1970. It was concluded that manure storage by stockpiling results in no significant change in quality if the stockpile is not disturbed during the storage period.

The quality of manure applied to the field disposal plots in the fall of 1969, 1970, and 1971 is presented in Table 7. The N, P, and VS content of the manure in 1970 was considerably higher than in 1969 and 1971 due to the lower precipitation during the year. Less dirt was worked into the manure pack by the hoofs of the cattle during this relatively dry year. For all three years, the quality of manure applied to the disposal plots was comparable with lot samples taken during the year. Additional characteristics of manure applied to the disposal plots are given in Section IX of this report.

SECTION VII

EFFECT OF ANAEROBIC LAGOON STORAGE ON RUNOFF QUALITY

GENERAL

As feedlot runoff cannot be discharged to a stream, it must be caught and stored in a reservoir until it can be treated prior to release or spread onto land. The natural treatment taking place in an anaerobic storage lagoon was evaluated.

METHODS AND PROCEDURES

A lagoon was constructed to capture all the runoff from one individual feedlot pen designated Area 119. The lagoon was 30.5 m x 36.6 m at the bottom and was 4 m deep. This pond retained all runoff from the area for runoff events of 1970. The only liquid lost from the pond was by evaporation or seepage. Samples were collected near the pond center from a raft. Samples were taken 15 cm below the surface and just above the bottom and analyzed by the procedures given in Section V of this report.

RESULTS AND DISCUSSION

The values of COD for the sample nearest the surface are plotted in Figure 1. The surface samples represent that part of the pond which would be effluent if a discharge were allowed or if it were taken off for irrigation. The early spring samples from the pond exhibited the greatest values of COD, N, and P. This was also true of the runoff, though as mentioned previously, ground temperature has an inverse effect upon COD. After a period of heavy rains in late May and early June, the COD in the pond was about 6000 mg/l. There was no significant runoff again until August 15. Within this period, the COD at the pond surface was reduced to about 2000 mg/l, or a reduction of about 65%. During this period, the lagoon contents were being reduced by seepage and evaporation which would result in a concentrating effect on the pollutional parameters. The concentrating effect would best be shown by what happened to the total solids. Total solids showed a gradual increase from about 4000 mg/l in the middle of June to about 7000 mg/l in the middle of August, with no significant inflow. Taking into account the concentrating effect, the effective COD removal would be

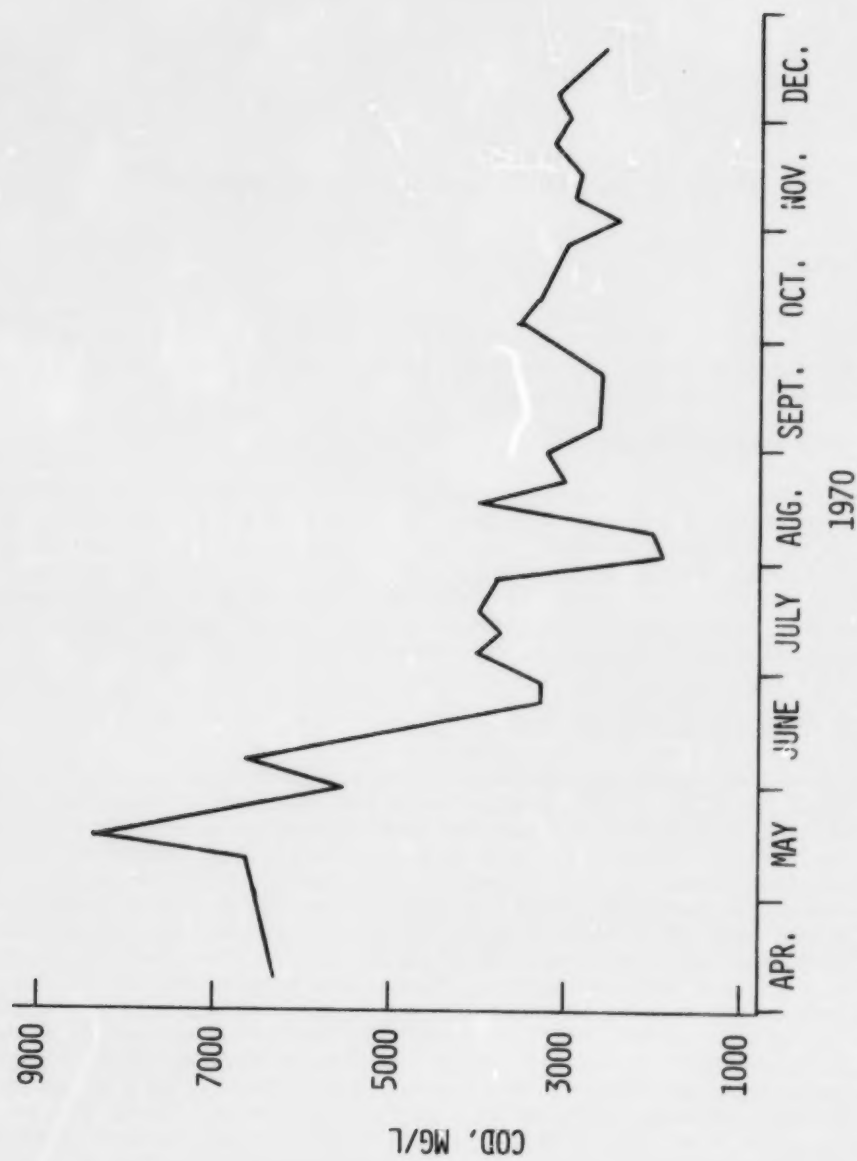


Figure 1. Influence of season on COD 15 cm below the surface of Lagoon 119.

even higher than that just stated. Total N and P did not show any great change during this period. The lower-level sample from the pond did not vary from the upper level sample until August. Samples taken after this time showed higher COD, N, P, and solids values. The results were variable, though, as a few cm change in sampling depth near the sludge zone significantly changed the results.

Solids in the pond bottom were actively decomposing, as indicated by the bubbling action that occurred. This would also have the effect of keeping the lagoon contents partially mixed. The odor from the pond was probably no greater than what might be expected from a feedlot pen covering the same area.

SECTION VIII

FEEDLOT RUNOFF DISPOSAL ONTO LAND

GENERAL

The most common method of disposal has been to apply lagoon water to adjacent crop and pasture land. High transportation costs dictate that maximum rates be applied to fields close to the source. The effect of furrow irrigation with beef feedlot lagoon water on growth and composition of corn forage and chemical properties of soil was evaluated.

METHODS AND PROCEDURES

Lagoon water was applied by furrow irrigation in increments of 5 cm and 10 cm during the summers of 1970, 1971, 1972, and 1973 to plots 9.1 m wide and 60 to 110 m long. Five treatments were replicated four times. In 1970 and 1973, the last 10-cm increment of lagoon water was not applied to the four plots receiving heaviest applications until after harvest. Inflow and outflow were measured on each plot. The average amounts applied after four years were calculated to be 0, 7, 13, 22, and 37 centimeters per year (cm/yr) for the four replications. The two replications that were sampled for soil core analysis had received an average of 0, 8, 17, 26, and 45 cm/yr by the fall of 1970; 0, 8, 15, 23, and 43 cm/yr by the fall of 1971; and 0, 7, 14, 20, and 41 cm/yr by the fall of 1972. Samples of the lagoon water were collected during each application and analyzed for Ca, Mg, Na, and K by standard atomic absorption and flame photometric procedures, for $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ by steam distillation procedures (Keeney and Bremner⁶⁷), and for soluble salts by resistance measurements using a Wheatstone bridge.

To compare composition of the material being applied at the study site with that found at other feedlots, samples were taken from 12 locations in Kansas during early July of 1970 and 1971 and were analyzed in the manner described above. The lagoons were sampled at four depths in 1970: 5, 50, 100, and 200 cm. Chemical composition did not vary with depth in 1970, so a single sample was taken at 15 cm from each lagoon in 1971.

All plots received a preplant irrigation in the spring of 1971 and 1972. Additional well water was applied during the growing seasons to the

control plots and to plots receiving the lower lagoon water treatments so all plots received approximately equal volumes of liquid. No chemical fertilizers were applied.

Corn silage yields (mechanical harvest) were recorded, and forage samples from each plot were analyzed for Ca, Mg, Na, and K by atomic absorption and flame photometry after a nitric-perchloric acid digestion. N and P were determined by steam distillation and colorimetric procedures, respectively, after a sulfuric acid digestion. The 1972 and 1973 forage were analyzed for $\text{NO}_3\text{-N}$ by hot-water extraction and subsequent analysis by steam distillation.

Composite surface soil samples (0 to 15 cm) were taken at 18 locations in each plot after harvest. Extracts from a water-saturated paste were analyzed for soluble salts by resistance measurements. Cores were taken after harvest to a depth of 2 m in 1970 and 3 m in 1971 and 1972 from plots in two replications. The surface meter of each core was divided into 10-cm increments and analyzed for extractable Ca, Mg, Na, and K by atomic absorption and flame photometry. For the 1970 and 1971 cores, the extraction procedure included an initial extraction with methanol to remove the cations not on exchange sites. This was followed by extraction with 1.0 N ammonium acetate, pH 7.0, to remove the exchangeable cations. The 1972 cores were extracted with ammonium acetate only. Except for Na, only insignificant concentrations were found in the methanol extract. The total cations extracted by these two methods are referred to as extractable Ca, Mg, Na, or K. The surface meter increments also were analyzed for Bray P-1 extractable P. The lower depths were divided into 20-cm increments and, along with the upper depths, analyzed for $\text{NO}_3\text{-N}$ by steam distillation techniques (Keeney and Bremner 67). The 1972 cores were analyzed for soluble salts to a depth of one meter by resistance measurements of extracts from water-saturated pastes.

RESULTS AND DISCUSSION

Lagoon Water Analyses

Results of analyses of the lagoon water applied are given in Table 8. Total salt concentration, indicated by the electrical conductivity, was high. Concentrations of the monovalent cations NH_4^+ , K^+ , and Na^+ were considered to be high. The high and low values of all measurements show how the composition of the lagoons of a single feedlot can vary. This variation was not accounted for in our interpretation of soil and plant measurements.

Table 9 includes the analyses of the lagoon samples taken at the 12 Kansas locations. Wide variation in composition of samples among lagoons each year was similar to variation of lagoon water applied. There was little correlation between the 1970 and 1971 data from the same locations. Lack of uniformity between lagoons and between years makes

Table 8. ELEMENTAL COMPOSITION AND ELECTRICAL CONDUCTIVITY OF BEEF FEEDLOT LAGOON WATER

	Electrical conductivity mmho/cm	Na	K	Ca	Mg	NH ₄ ⁺ -N mg/l	NO ₃ ⁻ -N	Total solids	COD	Volatile solids %
High	7.6	660	1840	615	239	179	63	18134	6445	44.4
Low	1.6	112	259	83	35	4	1	1879	593	27.1
Average	3.1	295	671	225	87	73	13	4771	1868	37.8

Table 9. ELEMENTAL COMPOSITION AND ELECTRICAL CONDUCTIVITY OF BEEF FEEDLOT RUNOFF
LAGOON SAMPLES TAKEN AT 12 LOCATIONS IN KANSAS DURING JULY, 1970 AND 1971

Location	Electrical Conductivity		Na		K		Ca		Mg		Total Inorganic N	
	1970 ^b	1971 ^c	1970 ^b	1971 ^c	1970 ^b	1971 ^c	1970 ^b	1971 ^c	1970 ^b	1971 ^c	1970 ^b	1971 ^c
	mmho/cm											
	ppm											
1	3.1	3.0	142	122	387	583	152	101	74	78	195	145
2	2.7	2.7	139	220	166	325	101	100	61	70	164	119
3	3.3	4.1	221	293	330	604	160	158	85	111	151	167
4	1.0	4.8	73	329	52	617	65	127	34	124	16	161
5	4.2	3.9	268	335	550	729	141	143	97	81	220	61
6	6.3	4.3	339	299	826	708	177	135	78	89	130	218
7	8.6	12.6	653	1320	1100	1920	523	310	153	171	366	543
8	12.6	4.2	1690	403	2030	458	403	136	189	82	207	127
9	7.3 ^a	---	834 ^a	---	752 ^a	---	212 ^a	---	112 ^a	---	221 ^a	---
10	---	10.6	---	1460	---	2210	---	108	---	235	---	136
11	---	1.4	---	317	---	483	---	101	---	64	---	133
12	---	6.0	---	500	---	750	---	187	---	170	---	143

^a Lagoon dry at sampling time.

^b The 1970 data are averages of samples taken at depths of 5, 50, 100 and 200 cm.

^c The 1971 data are from a single sample taken at a depth of 15 cm.

it essential that analysis of lagoon wastewater be known before disposal to predict how the material will affect soil properties and plant growth.

Effects on Soil Chemical Properties

Electrical conductivities of saturation extracts from 1970, 1971, and 1972 surface soil samples were linearly related to the accumulative depth of lagoon water applied (Figure 2). The EC values of plots receiving an average of 7 cm/yr were not much higher than those of the control plots. Plots receiving 13, 22, or 37 cm/yr had EC values generally higher than the control plots. Since the EC measurement is directly related to total water-soluble salt content of a soil, the three heaviest treatments provided more salts than could be used by the corn plants or leached lower into the profile. High values for the coefficient of multiple correlation squared (R^2) for all three years (0.878, 0.875, and 0.914) indicate good correlation between the EC measurement and accumulative amounts of lagoon water applied. This suggests that EC measurements could be used to estimate amounts of lagoon water that have been applied to a soil.

To improve the graphical presentation of the soil-core analysis data, measurements taken from two plots receiving the same treatment were averaged. Data points were further reduced by combining data from adjacent depth increments, so that in Figures 3, 4, 5, and 6 values are plotted for depths of 10, 30, 50 cm, etc., rather than at depths of 5, 15, 25, 35, 45, 55 cm, etc.

Figure 3 gives NO_3^- -N concentrations in the 1970, 1971, and 1972 soil cores. In 1970, all plots that received lagoon water had higher NO_3^- -N concentrations at the 10- and 30-cm depths than did control plots. No NO_3^- -N accumulated deeper than 30 cm in 1970. Soil cores taken in 1971 showed accumulations at 10-, 30-, and 50-cm depths at all disposal rates. The 23- and 43-cm/yr rates caused particularly high concentrations at 10- and 30-cm depths. A NO_3^- -N peak was found at 100 cm under the plots that received 43 cm/yr. In 1971, peaks were less well defined at 200 and 240 cm under the plots that had received lagoon water treatments of 15 and 43 cm/yr, respectively. By 1972, there was significant movement of NO_3^- -N to the 240-cm depth under plots that had received 20 and 41 cm/yr. Because the control plots received no additional N, their NO_3^- -N levels were lower than what would be expected in an irrigated soil being managed for maximum corn production. The two highest disposal rates were, therefore, the only treatments that caused significant accumulations of NO_3^- -N in the soil profiles.

All disposal rates caused extractable P to accumulate to a depth of 10 cm in the 1970, 1971, and 1972 soil cores (Figure 4). Movement to the 50-cm depth was found under plots receiving 41 cm/yr in 1972. The general lack of P movement indicates that the capacity of the soil to immobilize the added P had not been exceeded except possibly at the highest application rate.

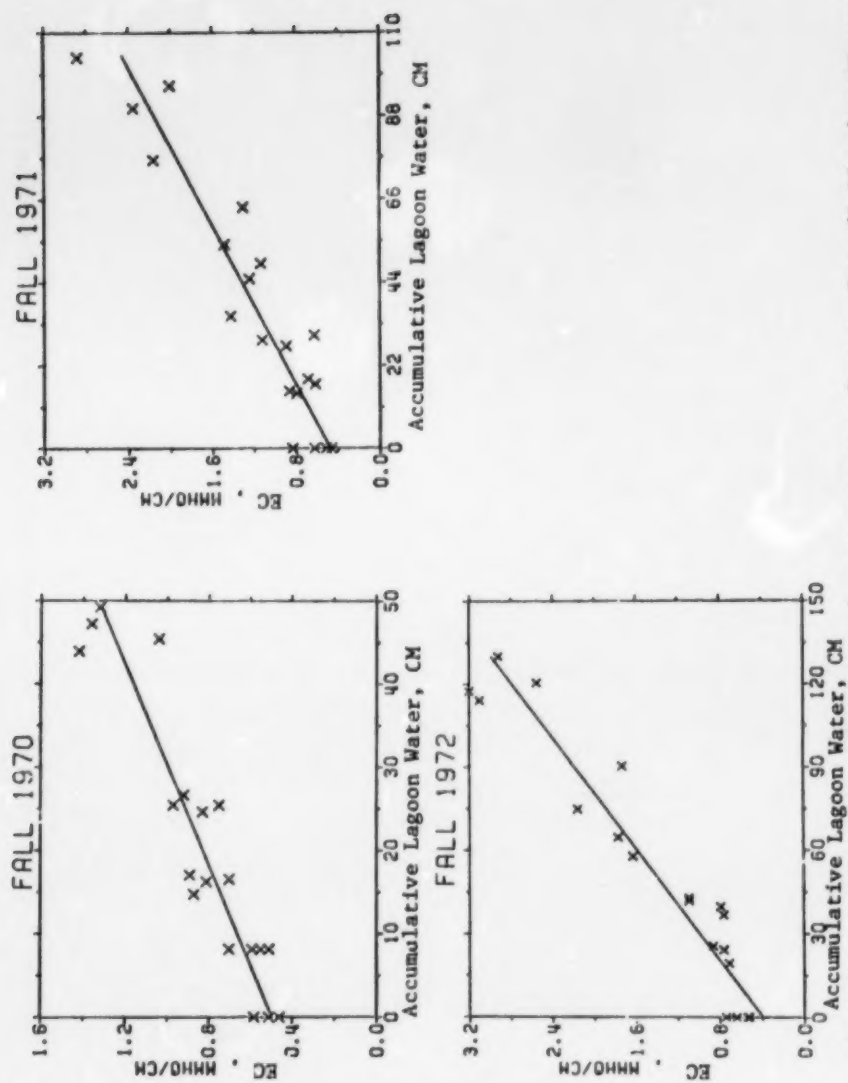


Figure 2. Electrical conductivity of saturated paste extracts from surface (0-15 cm) soil samples as affected by accumulative applications of beef feedlot lagoon water.

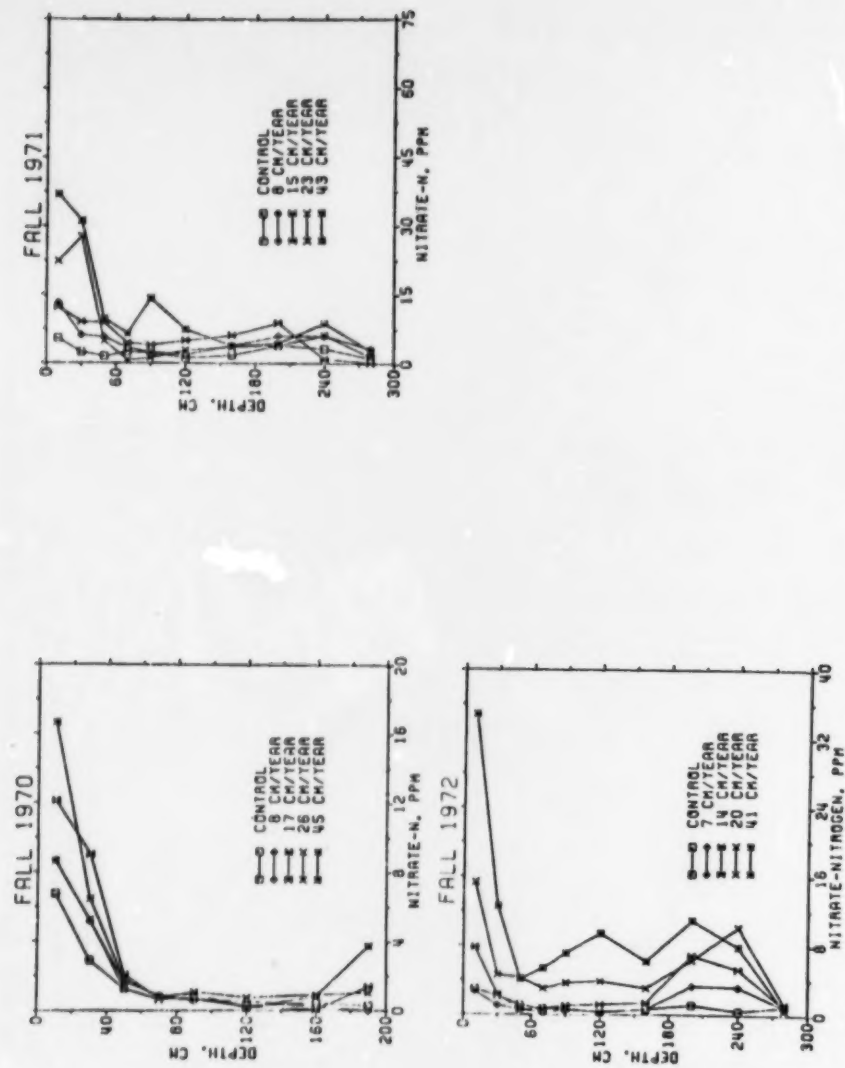


Figure 3. Nitrate-nitrogen content of soil cores as affected by depth and average yearly application rate of beef feedlot lagoon water.

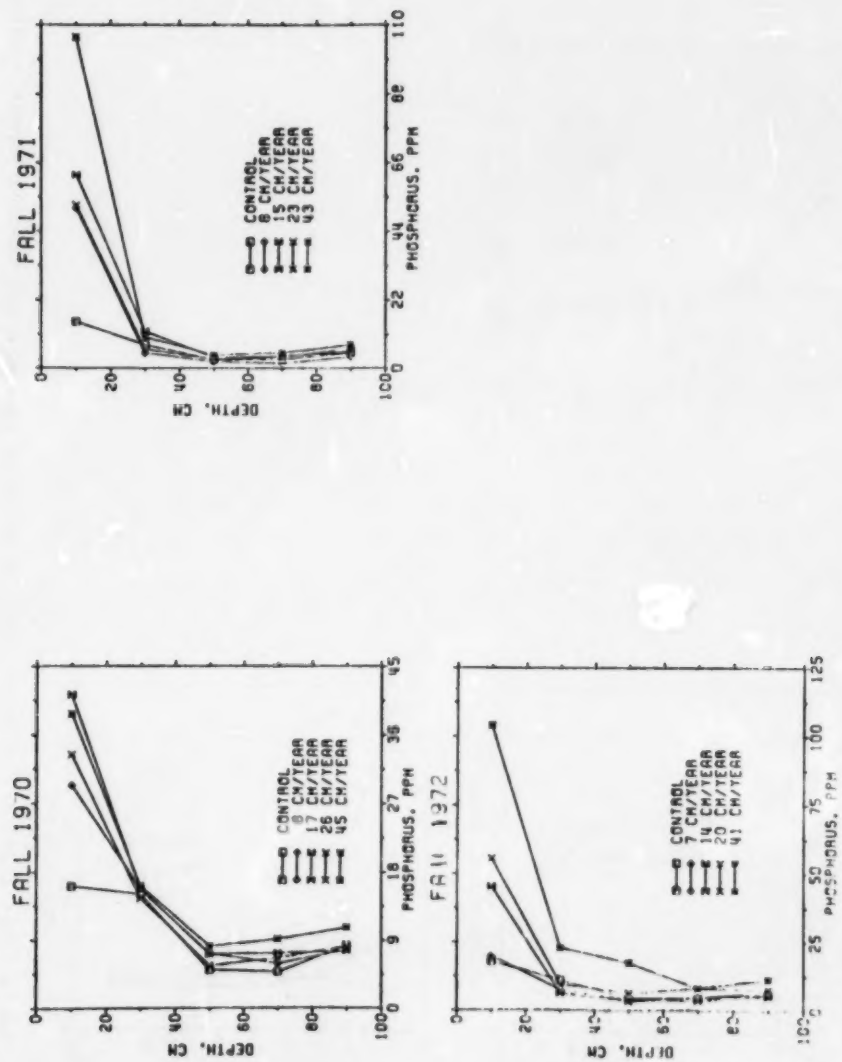


Figure 4. Bray P-1 extractable P content of soil cores as affected by depth and average yearly application rate of beef feedlot lagoon water.

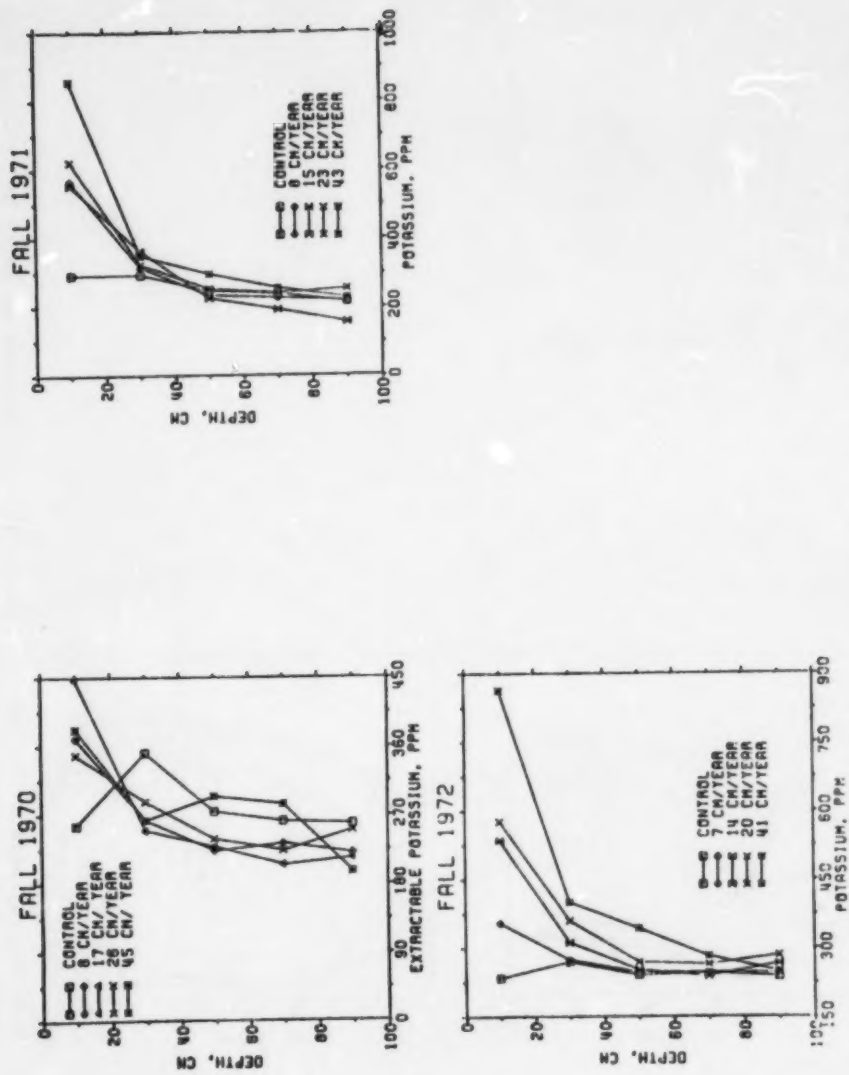


Figure 5. Extractable K content of soil cores as affected by depth and average yearly application rate of beef feedlot lagoon water.

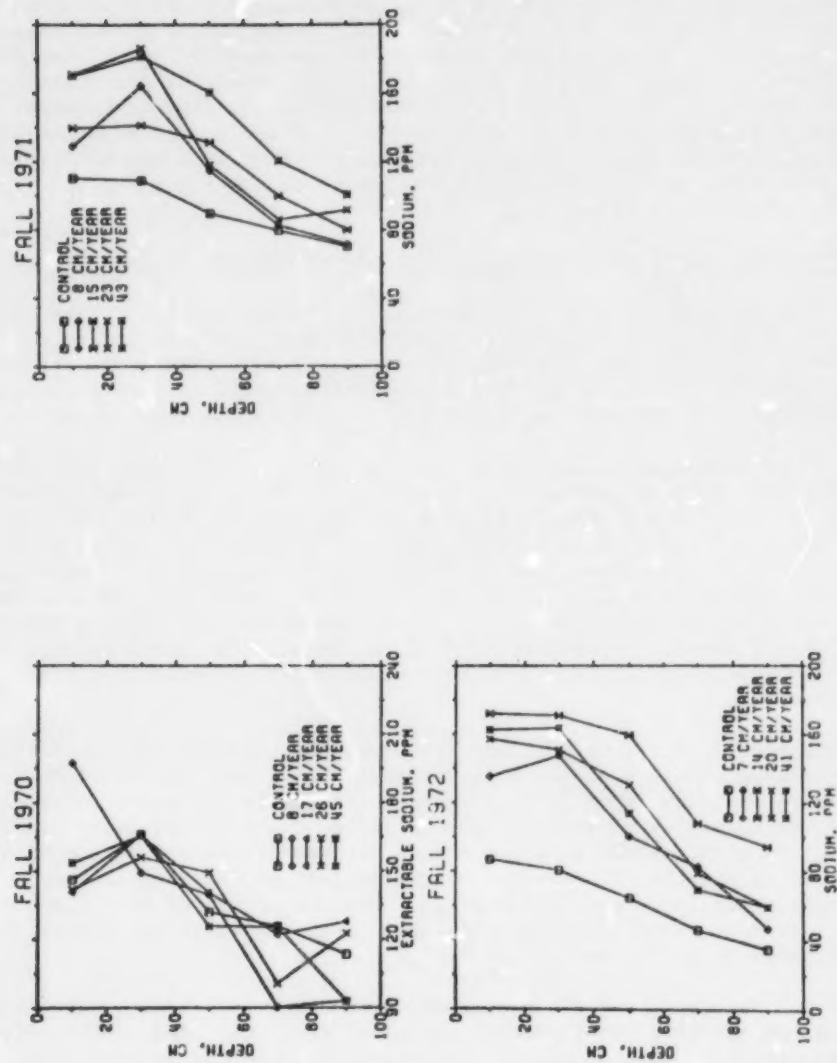


Figure 6. Extractable Na content of soil cores as affected by depth and average yearly application rate of beef feedlot lagoon water.

Analyses of the 1970 cores for extractable Na, K, Ca, and Mg and analyses of 1971 and 1972 cores for extractable Ca and Mg showed no trends due to treatment. Extractable K was increased to a depth of 10 cm in the 1971 cores and to 30 cm in the 1972 cores at all disposal rates (Figure 5). Movement below these depths was probably restricted by exchange reactions with clay colloids. Extractable Na accumulated at all depths in the 1971 and 1972 cores (Figure 6). Deeper movement of Na than K reflects greater competitiveness of K for cation exchange sites. Soluble salts, as indicated by the EC measurements of the 1972 soil cores, had increased throughout the top meter under plots receiving 14, 20, and 41 cm/yr (Figure 7).

Effect on Yield, Elemental Uptake And NO_3^- -N Content Of Corn Forage

Thirty-five centimeters of lagoon water had been applied to the plots receiving heaviest treatments by the time the 1970 corn forage was harvested. There was a general linear trend in yield due to treatment in 1970 (Figure 8). That positive effect on yield in 1970 probably resulted from increased soil fertility (nutrients in the lagoon water).

Maximum yields were recorded at the 26-, 22-, and 29-cm/yr rate in 1971, 1972, and 1973, respectively. Yields fell off at higher application rates, which gave a quadratic relationship between accumulative applications and yield in 1971, 1972, and 1973 (Figure 8). The initial increase in yield again can be attributed to improved soil fertility, while the yield decline at the higher rates likely resulted from salt buildup in the soil (Figure 2). Yield depression was less in 1973 probably because of higher rainfall that year. The yield decline was relative; all plots receiving lagoon water yielded more than control plots.

Uptake of N, P, K, Ca, Mg, and Na was calculated from the yield and elemental analyses of the corn forage. Linear and quadratic coefficients and intercepts from a regression analysis on uptake as affected by the accumulative applications of lagoon water are presented in Table 10. In 1970, uptake of all elements increased linearly with applications as did the 1970 yield. Uptake in 1971 and 1972 was a quadratic function of treatment as was yield. Maximum uptake of most elements occurred at about the same application rate that gave the highest yield (Figures 8, 9, 10, and 11).

The concentration of NO_3^- -N increased linearly with accumulative treatment in the 1972 and 1973 corn forage (Figure 12). Two of the values measured were high enough to be considered dangerous to livestock if ingested.

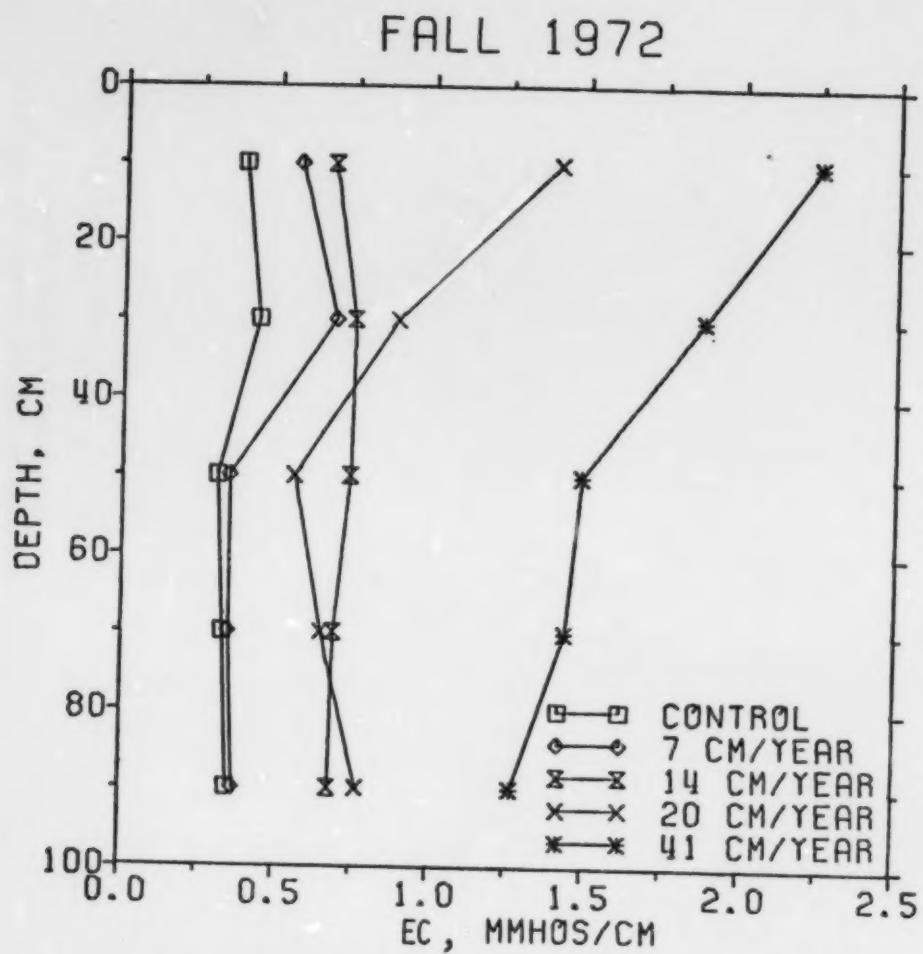


Figure 7. Electrical conductivity of saturated paste extracts from soil cores as affected by depth and average yearly application rate of beef feedlot lagoon water.

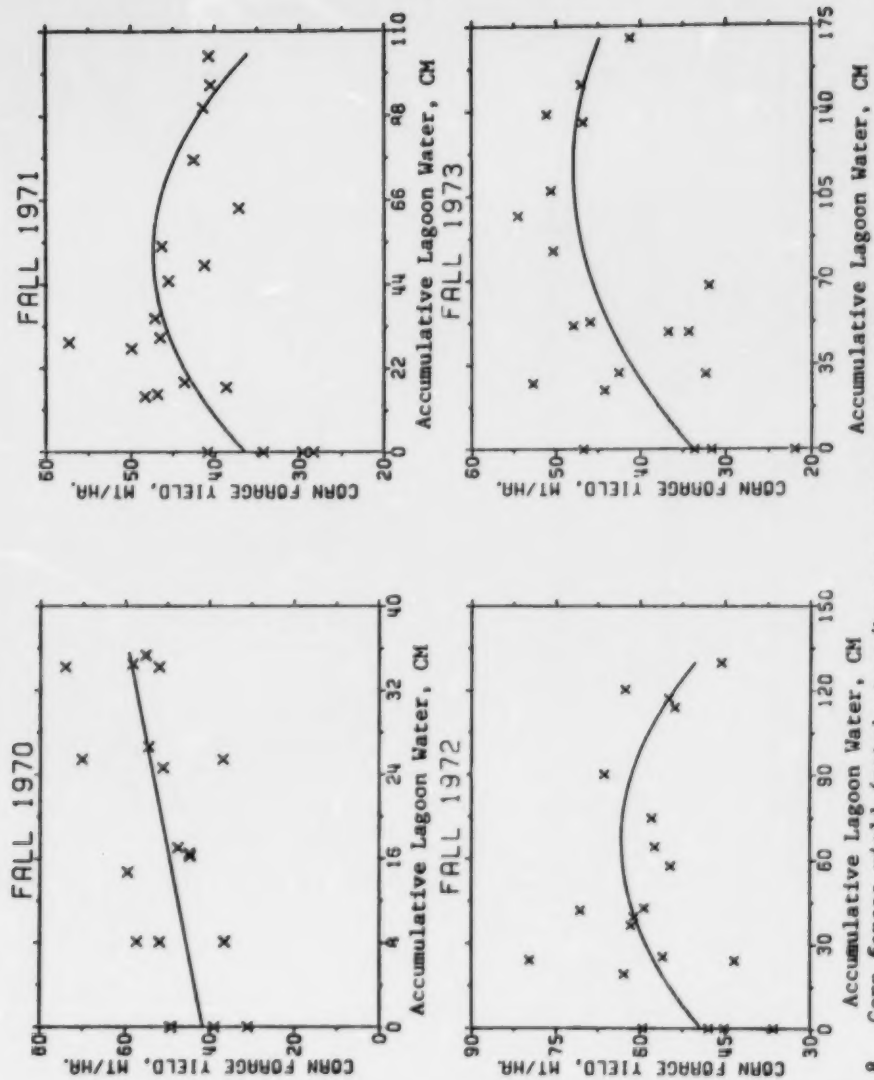


Figure 8. Corn forage yield (metric tons/hectare, corrected to 30% dry matter) as affected by accumulative applications of beef feedlot lagoon water.

Table 10. CORN FORAGE YIELD, ELECTRICAL CONDUCTIVITY OF SOIL SATURATION EXTRACTS (EC), AND UPTAKE BY CORN OF INDICATED ELEMENTS

Measurement (y) ^a	R ²	a ^a	b ^a	c ^a	F
1970					
Yield (MT/ha.)	0.316	0.0	0.49 ^b	41.5	8.30 ^b
N uptake (kg/ha.)	0.482	0.0	2.75 ^b	98.9	16.75 ^b
P uptake (kg/ha.)	0.107	0.0	0.388	33.7	2.15 ^b
K uptake (kg/ha.)	0.197	0.0	1.60 ^b	162.0	4.41 ^b
Ca uptake (kg/ha.)	0.0	---	---	---	0.0
Mg uptake (kg/ha.)	0.186	0.0	0.0890 ^b	19.8	4.12 ^b
Soil EC (mmho/cm)	0.878	0.0	0.0166 ^b	0.495	129.84 ^b
1971					
Yield (MT/ha.)	0.372	-0.00410 ^b	0.425 ^b	36.3	5.04 ^b
N uptake (kg/ha.)	0.574	-0.0221 ^b	2.63 ^b	85.0	16.18 ^b
P uptake (kg/ha.)	0.290	-0.00256 ^b	0.264 ^b	17.2	4.73 ^b
K uptake (kg/ha.)	0.079	-0.000190	0.367	131.0	1.16
Ca uptake (kg/ha.)	0.157	-0.00280	0.301	20.9	2.07
Mg uptake (kg/ha.)	0.188	-0.00139	0.137	14.8	2.96 ^b
Na uptake (kg/ha.)	0.387	-0.000212 ^b	0.0261 ^b	0.649	6.39 ^b
Soil EC (mmho/cm)	0.875	0.0	0.0191 ^b	0.470	125.56 ^b
1972					
Yield (MT/ha.)	0.269	-0.0032 ^b	0.426 ^b	49.2	3.13
N uptake (kg/ha.)	0.584	-0.0177 ^b	2.91	96.3	11.96 ^b
P uptake (kg/ha.)	0.161	-0.00179	0.270	29.3	1.63
K uptake (kg/ha.)	0.465	-0.0183 ^b	2.83 ^b	164.0	7.40 ^b
Ca uptake (kg/ha.)	0.212	-0.00237	0.350	28.9	2.28
Mg uptake (kg/ha.)	0.132	-0.00117	0.170	21.8	1.30
Na uptake (kg/ha.)	0.333	---	0.00415 ^b	0.558	8.99 ^b
Soil EC (mmho/cm)	0.914	---	0.0200 ^b	0.391	190.87 ^b
Forage Nitrate-Nitrogen (ppm)	0.561	---	5.29 ^b	-8.86	23.04 ^b
1972					
Yield (MT/ha.)	0.327	-0.00106	0.245 ^b	33.8	4.13 ^b
Forage Nitrate-Nitrogen (ppm)	0.482	---	2.26 ^b	75.7	16.76 ^b

^a Data expressed as factors of a regression equation: $y = ax^2 + bx + c$
^b Significant at the 0.05 level.

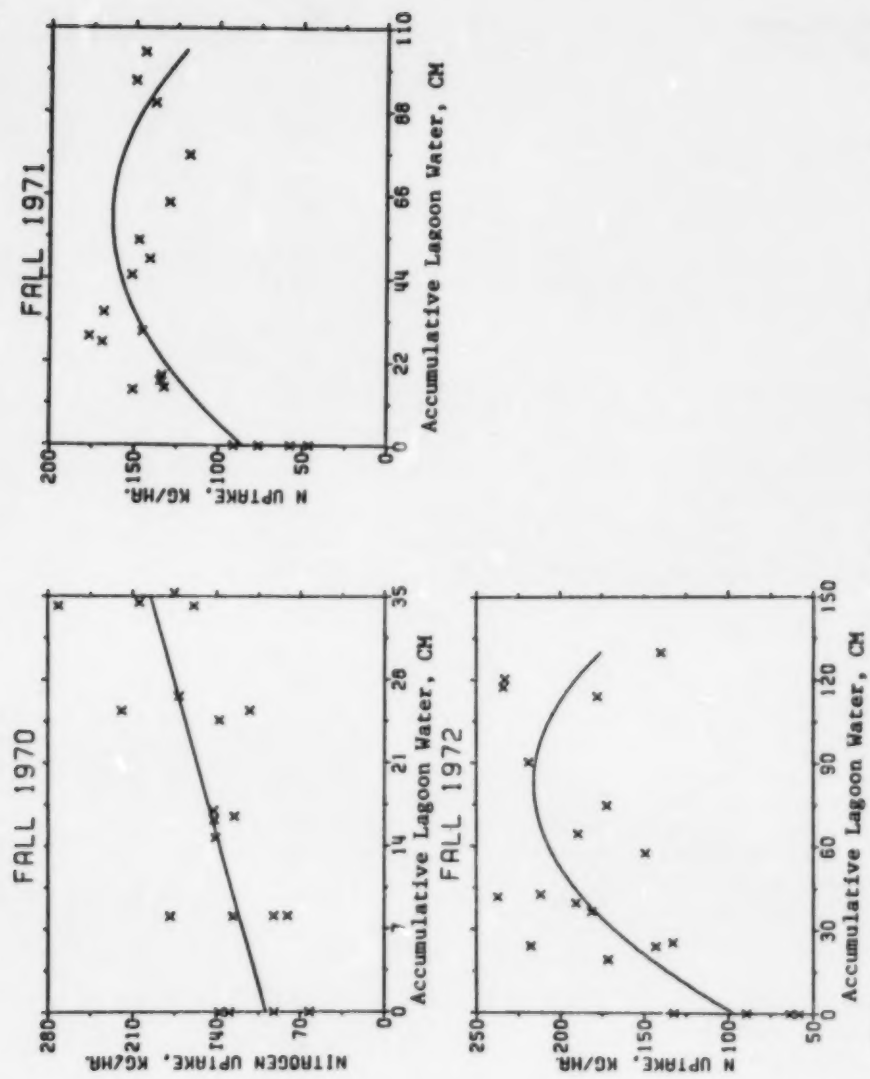


Figure 9. Uptake of N by corn forage as affected by accumulative applications of beef feedlot lagoon water.

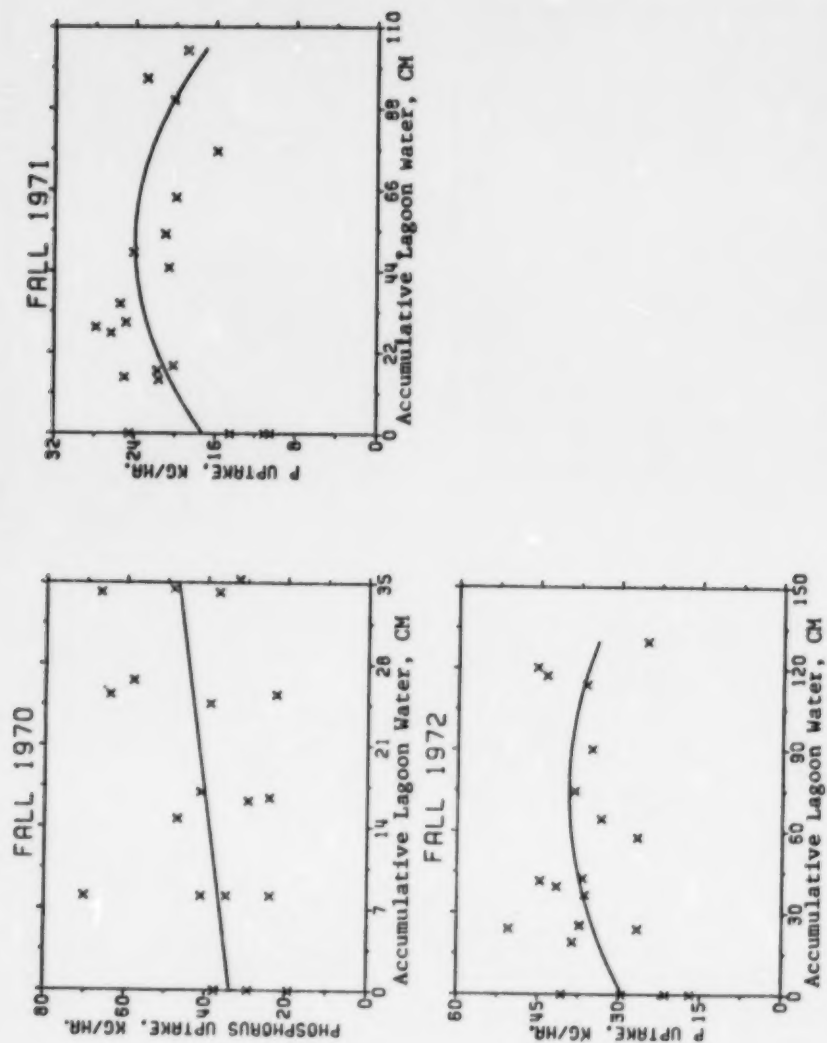


Figure 10. Uptake of P by corn forage as affected by accumulative applications of beef feedlot lagoon water.

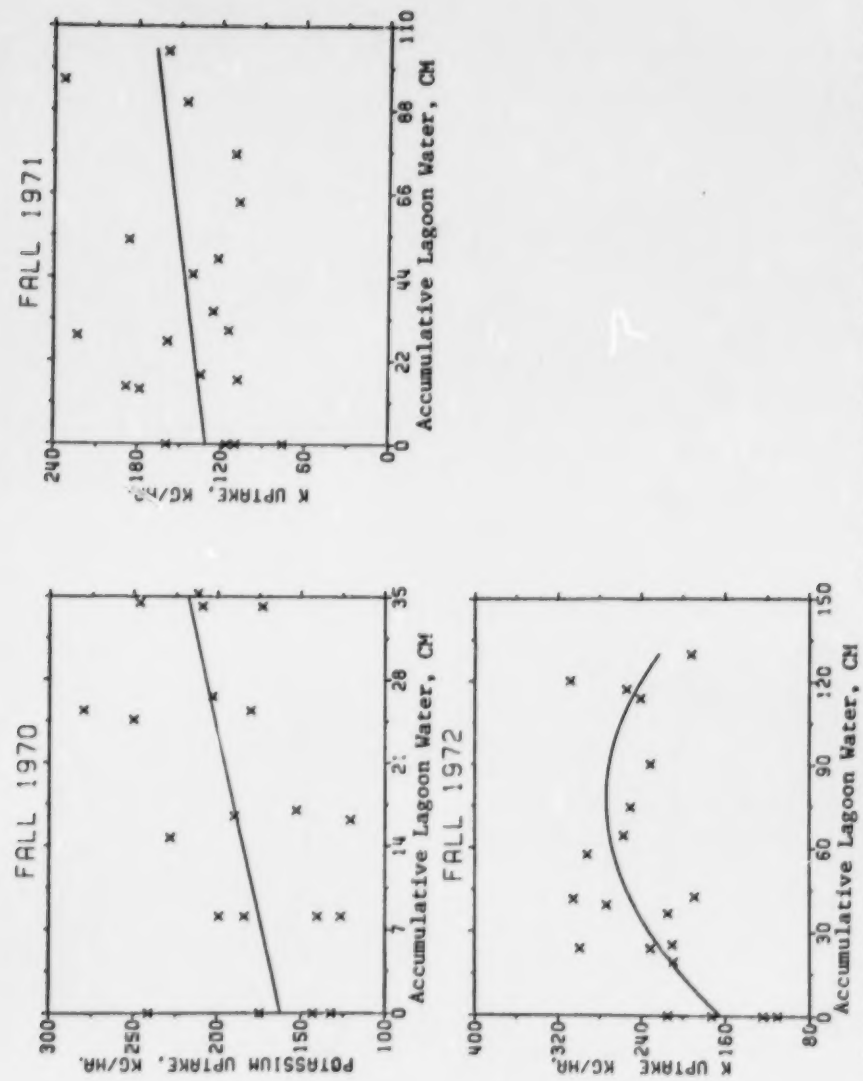


Figure 11. Uptake of K by corn forage as affected by accumulative applications of beef feedlot lagoon water.

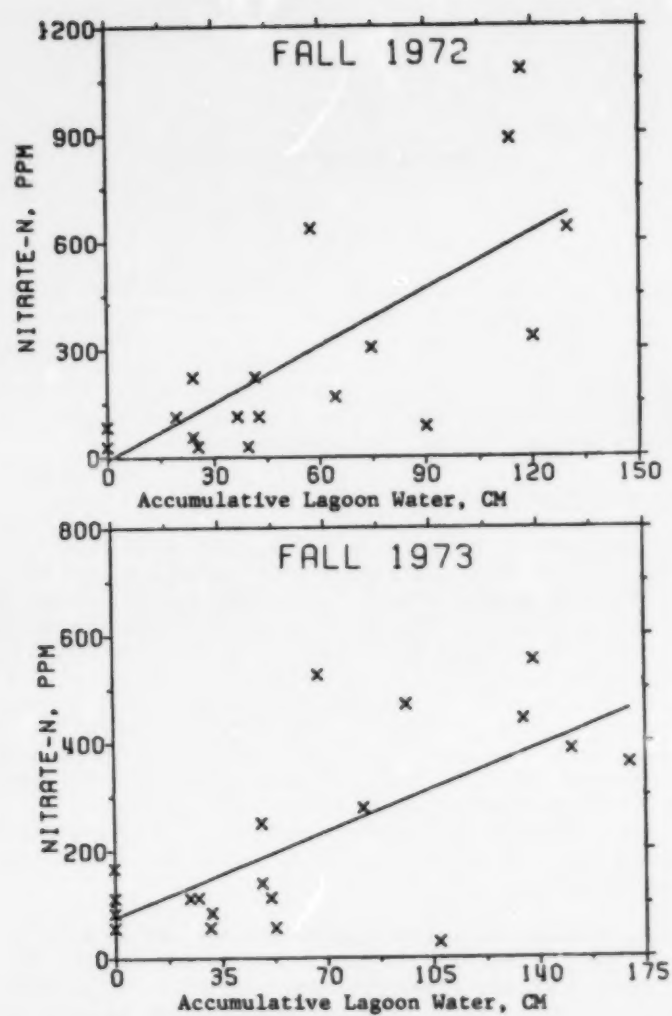


Figure 12. Nitrate-N content (dry weight basis) of corn forage as affected by accumulative applications of beef feedlot lagoon water.

SECTION IX

MANURE DISPOSAL ONTO LAND

GENERAL

Application of animal wastes onto land has been used primarily to recover the plant nutrients and to increase crop production. Land application as a means of disposal has not been practiced to any large extent. The effects of a wide range of yearly and residual treatments of solid beef feedlot manure on the growth of furrow-irrigated corn forage, on corn forage composition and nutrient uptake, and on the chemical properties of soil were evaluated.

METHODS AND PROCEDURES

Manure was applied by manure spreaders in the falls of 1969, 1970, 1971, and 1972 to 24 plots 9.1 m wide and 64 m long (yearly treatments). Twelve plots received a single manure application in the fall of 1969 (residual treatments). The original experimental design was six yearly and three residual treatments replicated four times in a randomized, complete block structure with a control plot in each block that received no manure or chemical fertilizer. Accurate duplicate measurement of the large tonnages of manure needed proved impractical. The actual tonnages applied to each plot were measured by weighing what fell on a 1.858-m² plastic tarp. Variation from the intended treatments resulted in a fairly uniform distribution of 114 to 2750 accumulative, dry, MT/ha. of manure being applied to the plots receiving the yearly treatments after four years and from 123 to 590 MT/ha. being applied to the residual treatment plots.

Grab samples were taken from the manure applied to each plot in 1969, 1971, and 1972. The samples were analyzed for Ca, Mg, Na, and K by atomic absorption and flame photometry after a nitric-perchloric acid digestion and for N and P by steam distillation and colorimetric procedures after a sulfuric acid digestion.

Corn forage yields (mechanical harvest) were recorded, and samples from each plot were analyzed in the same manner as the manure samples. In addition, NO₃⁻-N was determined by hot water extraction and subsequent analysis by steam distillation (Keeney and Bremner⁶⁷). The corn was

furrow irrigated during the summers with approximately 41 cm/yr of well water and received additional preplant irrigations of approximately 13 cm in 1971 and 1972.

Composite surface soil samples (0-15 cm) were taken at 18 locations in each plot before preplant irrigation and corn planting in the spring of 1972 and 1973 and again after harvest but before the application of manure in the fall of 1970, 1971, and 1972. The EC of extracts from water-saturated pastes of the soil samples was determined by a resistance meter.

Soil cores were taken from each plot in two replications to depths of 1, 1, and 3 m in the spring of 1970, 1971, and 1972, respectively, before preplant irrigation and corn planting. After harvest but before the application of manure, soil cores were taken from the same plots to depths of 2, 3, and 3 m in the fall of 1970, 1971, and 1972, respectively. The surface meter of each core from both samplings in 1970 and 1971 and the fall sampling in 1972 were divided into 10-cm increments and analyzed for Bray-P-1 extractable P and extractable Ca, Mg, Na, and K. The cation extraction procedure for the 1970 and 1971 cores included an initial extraction with methanol to remove cations not on exchange sites. This was followed by extraction with 1.0 N ammonium acetate, pH 7.0, to remove the exchangeable cations. The fall 1972 cores were extracted with ammonium acetate only. Except for Na, only insignificant concentrations were found in the methanol extract. The total cations extracted by these two methods are referred to as extractable Ca, Mg, Na, or K. Final measurements for P were made by colorimetric procedures, for Na and K by flame photometry, and for Ca and Mg by atomic absorption. The lower depths of all cores were divided into 20-cm increments and, along with the upper depths, analyzed for NO_3^- -N and NH_4^+ -N by steam distillation technique (Keeney and Bremner⁶⁷).

RESULTS AND DISCUSSION

Manure Analysis

The analysis of the manure applied is given in Table 11. The high and low values show how the manure from a single feedlot can vary. This variation indicates that analysis of manure should be known before disposal to predict how the material will affect soil properties and plant growth.

Effects of Yearly Treatments on Soil Chemical Properties

Electrical conductivities of saturation extracts from surface soil samples were linearly related to the accumulative MT/ha. of manure applied at all sampling dates. The highest EC values (Figure 13) were measured from the spring samplings of 1972 (18.9 mmho/cm) and 1973 (12.0 mmho/cm). In 1973 large increases in EC were measured only in plots that had received greater than 1200 MT/ha. This means that manure at

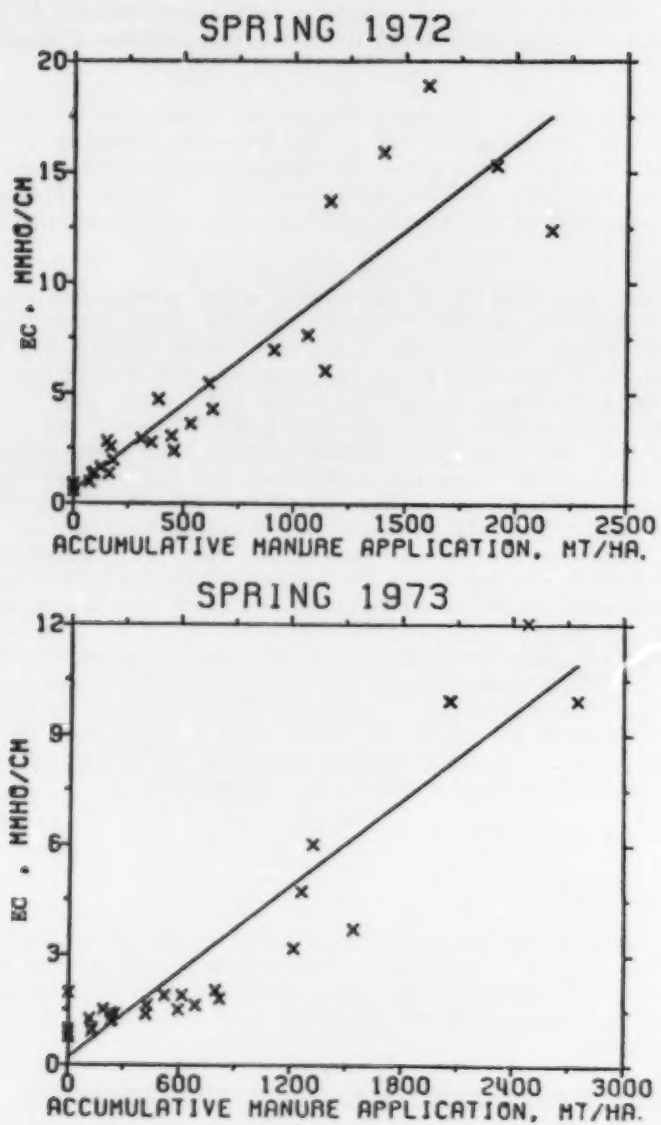


Figure 13. Electrical conductivity of saturated paste extracts from surface (0 to 15 cm) soil samples as affected by accumulative applications of beef feedlot manure (dry weights) that began in 1969.

Table 11. ANALYSIS OF BEEF FEEDLOT MANURE APPLIED TO DISPOSAL PLOTS

Year	H ₂ O	N	P	K	Ca	Mg	Na
percent of dry weights							
1969 average ^a	23.7	1.04	0.41	1.09	0.78	0.39	0.23
1971 average ^b	13.6	0.89	0.57	0.97	0.98	0.42	0.25
1972 average ^b	24.3	0.84	0.57	1.37	0.99	0.42	0.29
Sample high ^c	39.9	1.59	0.80	1.77	1.36	0.50	0.49
Sample low ^c	4.6	0.61	0.31	0.30	0.36	0.30	0.15
3-Year average	20.5	0.92	0.52	1.14	0.92	0.41	0.26

^a Averages of 36 samples.^b Averages of 24 samples.^c High and low values are from the 84 samples.

those rates provided more salts than could be utilized by the corn plants or leached lower into the profile. Plots receiving less than 800 MT/ha. by 1973 showed a gradual but not excessive buildup of soluble salts. Since the fall samplings were taken after maximum leaching of soluble salts by summer irrigations and yearly rainfall, their EC values were lower than those of the spring sampling of the same year. The high R^2 values found by regression analysis (Table 12) for all sampling dates indicated that this measurement was highly correlated to the accumulative MT/ha. of manure applied and that it could be used as a management tool to monitor the salt status of disposal fields and to estimate the amount of manure that has been applied to a soil.

To improve the graphical presentation of the soil-core analysis data from plots receiving yearly treatments, measurements taken from two plots receiving the same treatment were averaged and the treatments designated on Figures 14, 15, 16, and 17 by the average accumulative MT/ha. that had been applied to the two plots up to the sampling date. Data points were further reduced by combining data from adjacent depth increments, so that values are plotted for depths of 10, 30, 50 cm, etc., rather than at depths of 5, 15, 25, 35, 45, 55 cm, etc.

The NO_3^- -N analysis for the spring and fall 1972 cores, both taken after three years of applications, is given in Figure 14. All but the lowest

Table 12. CORN FORAGE YIELD, UPTAKE BY CORN OF INDICATED ELEMENTS,
CORN PLANT POPULATION, NITRATE -N CONTENT OF CORN FORAGE, AND ELECTRICAL
CONDUCTIVITY OF SURFACE SOIL SATURATION EXTRACTS AS AFFECTED BY ACCUMULATIVE
YEARLY APPLICATIONS OF BEEF FEEDLOT MANURE (DRY MT/ha.) THAT BEGAN IN THE FALL OF 1969

Measurement	R ²	a ^a	b ^a	c ^a	F
1970					
Yield (MT/ha.)	0.248	-0.000127 ^b	0.0583 ^b	45.4	6.10 ^b
N uptake (kg/ha.)	0.315	-0.000705 ^b	0.436 ^b	130.0	8.52 ^b
P uptake (kg/ha.)	0.162	-0.000109 ^b	0.0731 ^b	28.4	3.58 ^b
K uptake (kg/ha.)	0.142	-0.000770 ^b	0.418 ^b	191.0	3.06 ^b
Ca uptake (kg/ha.)	0.155	-0.0000956 ^b	0.0548 ^b	27.7	3.40 ^b
Mg uptake (kg/ha.)	0.164	---	-0.00845 ^b	21.5	7.48 ^b
Population (No./ha.)	0.435	---	-17.4 ^b	48100.0	29.22 ^b
Fall Soil EC (mmho/cm)	0.766	---	0.00389 ^b	0.558	124.56 ^b
1971					
Yield (MT/ha.)	0.491	-0.0000446 ^b	0.0268	37.5	12.06 ^b
N uptake (kg/ha.)	0.376	-0.000245 ^b	0.214 ^b	123.0	7.55 ^b
P uptake (kg/ha.)	0.297	-0.000487 ^b	0.0427 ^b	23.6	5.26 ^b
K uptake (kg/ha.)	0.113	-0.000150	0.0123	301.0	1.59 ^b
Ca uptake (kg/ha.)	0.247	-0.0000298	0.217	22.1	4.07 ^b
Mg uptake (kg/ha.)	0.020	-0.0000119	0.01162	14.7	0.0
Na uptake (kg/ha.)	0.023	-0.00000065	0.000921	0.882	0.30
Population (No./ha.)	0.418	0.00892 ^b	-12.1 ^b	53000.0	8.97 ^b
Fall Soil EC (mmho/cm)	0.782	---	0.00372 ^b	0.575	93.37 ^b
Forage Nitrate-N (ppm)	0.539	-0.000528 ^b	0.726 ^b	10.5	14.59 ^b

Table 12 (Continued). CORN FORAGE YIELD, UPTAKE BY CORN
OF INDICATED ELEMENTS, CORN PLANT POPULATION, NITRATE -N CONTENT OF CORN FORAGE,
AND ELECTRICAL CONDUCTIVITY OF SURFACE SOIL SATURATION EXTRACTS AS AFFECTED BY ACCUMULATIVE
YEARLY APPLICATIONS OF BEEF FEEDLOT MANURE (DRY MT/ha.) THAT BEGAN IN THE FALL OF 1969

Measurement	R ²	a ^a	b ^a	c ^a	F
1972					
Yield (MT/ha.)	0.480	---	-0.0153 ^b	60.2	24.03 ^b
N uptake (kg/ha.)	0.108	-0.0000278	0.0304	183.0	1.52
P uptake (kg/ha.)	0.084	-0.00000739	0.00971	37.1	1.14
K uptake (kg/ha.)	0.024	-0.0000176	0.0170	251.0	0.31
Ca uptake (kg/ha.)	0.156	---	-0.00678 ^b	29.7	4.81 ^b
Mg uptake (kg/ha.)	0.165	---	-0.00313 ^b	18.9	5.14 ^b
Na uptake (kg/ha.)	0.088	0.000000408	-0.000549	0.921	1.20
Population (No./ha.)	0.355	---	-2.80 ^b	57400.0	14.28 ^b
Spring Soil EC (mmho/cm)	0.840	---	0.00785 ^b	0.580	136.01 ^b
Fall Soil EC (mmho/cm)	0.804	---	0.00362 ^b	0.554	106.44 ^b
Forage Nitrate-N (ppm)	0.178	-0.000562 ^b	1.10	518.0	2.71
1973					
Yield (MT/ha.)	0.512	-0.00000930 ^b	0.0139	42.4	13.10 ^b
Population (No./ha.)	0.308	---	-4.99 ^b	45900.0	11.59 ^b
Spring Soil EC (mmho/cm)	0.882	---	0.00390 ^b	0.195	194.71 ^b
Forage Nitrate-N (ppm)	0.142	---	0.128 ^b	376.0	4.30 ^b

^a Data are expressed as factors of a regression equation: $y = ax^2 + bx + c$

^b Significant at the 0.05 level.

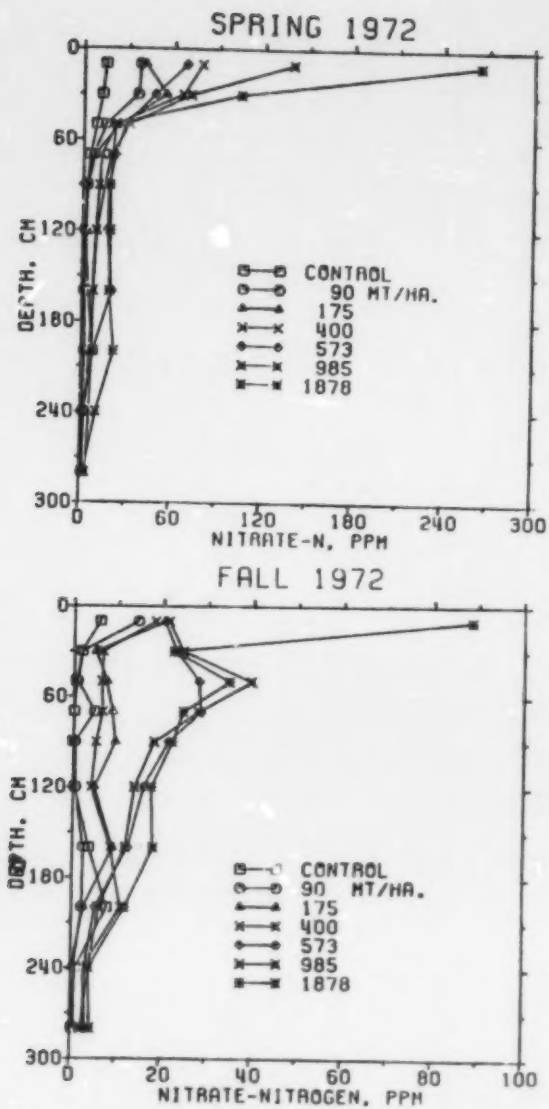


Figure 14. Nitrate-N content of soil cores as affected by depth and average accumulative applications of beef feedlot manure (dry weights) that began in 1969.

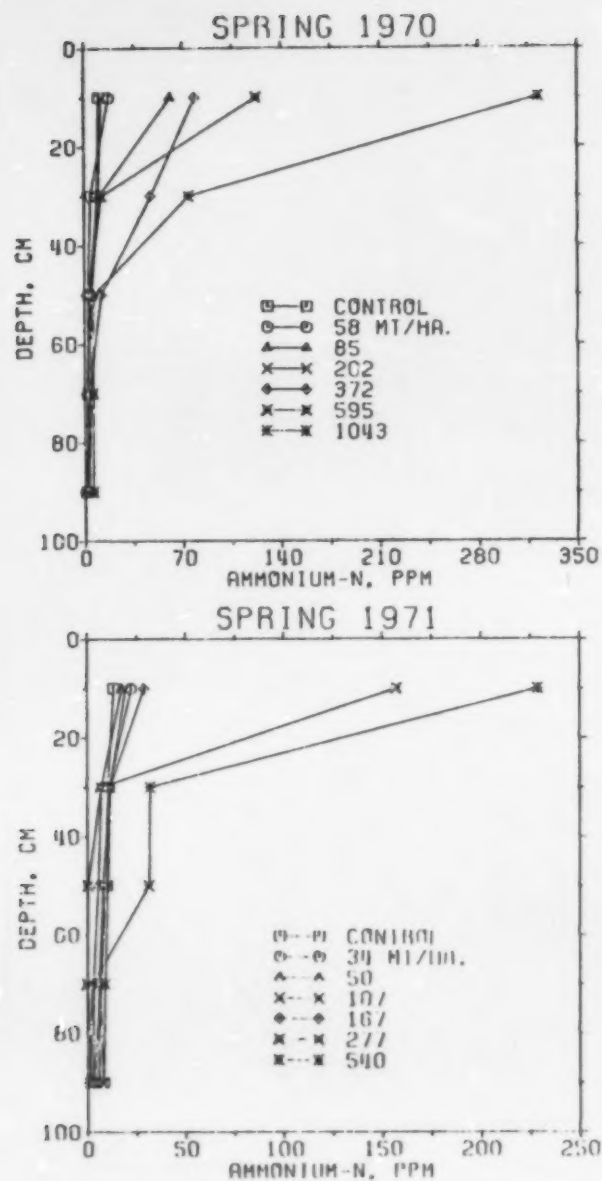


Figure 15. Ammonium-N content of soil cores as affected by depth and average accumulative applications of beef feedlot manure (dry weights) that began in 1969.

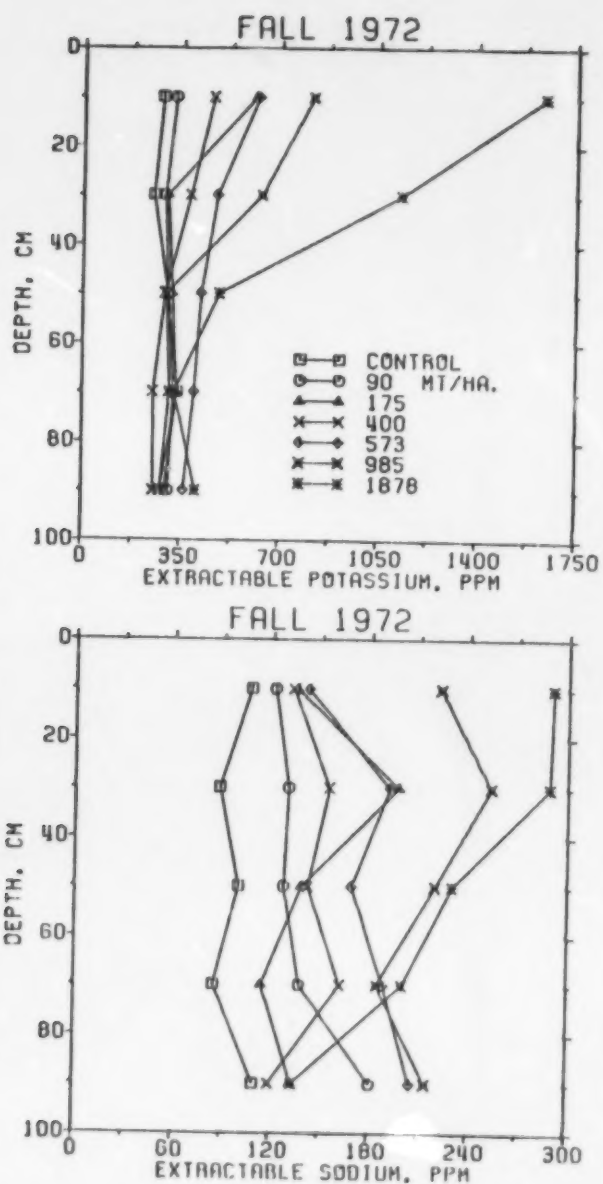


Figure 16. Extractable Na and K of soil cores as affected by depth and average accumulative applications of beef feedlot manure (dry weights) that began in 1969.

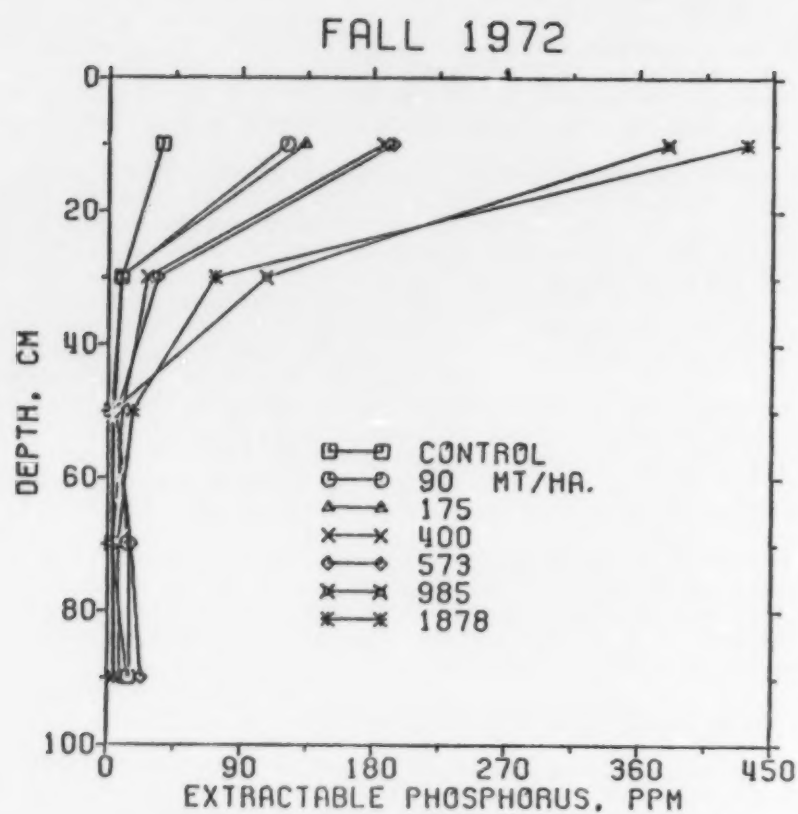


Figure 17. Extractable P of soil cores as affected by depth and average accumulative applications of beef feedlot manure (dry weights) that began in 1969.

treatment was supplying N in excess of what could be removed by the corn forage. This excess N was nitrified into NO_3^- -N and became subject to leaching. The concentrations of NO_3^- -N in the surface 30 cm of the spring 1972 cores show that large amounts of this anion had come into the soil solution. Leaching by irrigation water and plant uptake had lowered the surface 30-cm concentrations by the fall of 1972. Relative to that found under the control plots, all treatments except the lowest one showed evidence of having caused NO_3^- -N movement to 160 cm in the fall 1972 cores. Less well defined peaks are found at the 200-cm depth of the spring and fall 1972 cores taken from plots receiving the heaviest treatment. NO_3^- -N analysis of cores taken in 1970 and 1971 show accumulations and sequential movement (to 160 cm) that were both generally greater under plots receiving the two heavier treatments.

Ammonium -N concentrations were found to be high in the surface 30 cm of cores taken in the spring (Figure 15). Ammonium toxicity could have been a contributing factor in lowered plant populations in some years (Figure 18). Extractable K content of soil cores was not affected by the lowest treatment at any date. All higher treatments caused accumulations of K in the surface 30 cm, the magnitudes being greater under the higher treatments. K increased at the 50-cm depth under plots receiving the heaviest treatment at the fall 1971 and 1972 (Figure 16) samplings. Movement of K was probably restricted by cation-exchange reactions. Na is less competitive for cation exchange sites and was leached to lower depths. Analysis of the fall 1972 cores shows that all treatments had increased Na throughout the top meter relative to the control (Figure 16). No trend due to treatment could be found in the analysis of soil cores for extractable Ca or Mg.

Extractable P was found to have accumulated in the fall 1972 cores at the 10-cm depth at all treatment rates, and at the 30-cm depth in plots receiving the highest treatment (Figure 17). The lack of P movement below 30 cm indicates that the capacity of the soil to immobilize the added P had not yet been exceeded.

Effects of Yearly Treatments on Corn

Corn forage yield was enhanced by the lower and intermediate treatments and depressed by the higher treatments all four years (Figure 19). This quadratic effect was least apparent in the 1972 yields. The positive effect on yield can be explained by improved soil fertility since no nutrients were added to control plots. The negative effect was probably due to the salt buildup in the soils receiving the heavier treatments. The depression of yield by the higher rates in 1970, 1972, and 1973 could partially be explained by lowered germination and/or seedling growth because corn plant populations were decreased in those years (Figure 18). Maximum yields, predicted from yield equations given in Table 12, occurred at accumulative application rates of 230, 300, and 747 MT/ha. in 1970, 1971, and 1973, respectively. These application rates are equivalent to applications of 230, 150, and 187 metric tons

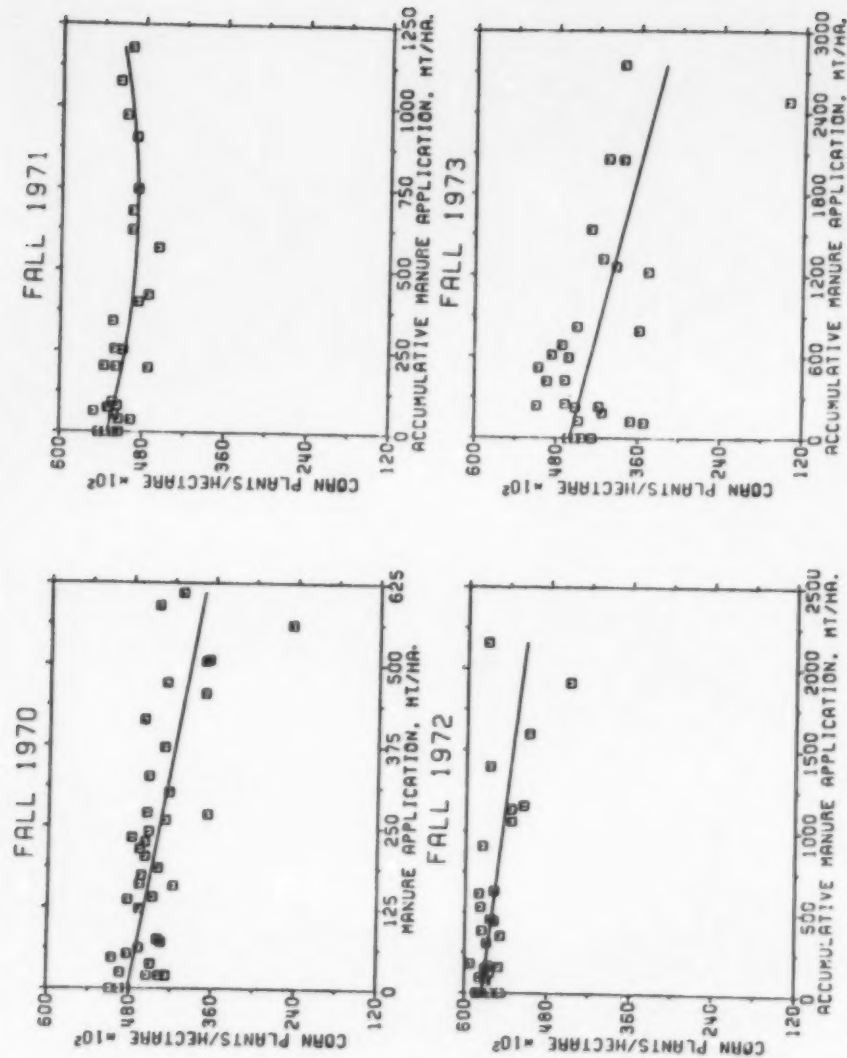


Figure 18. Corn plant populations as affected by accumulative applications of beef feedlot manure (dry weights) that began in 1969.

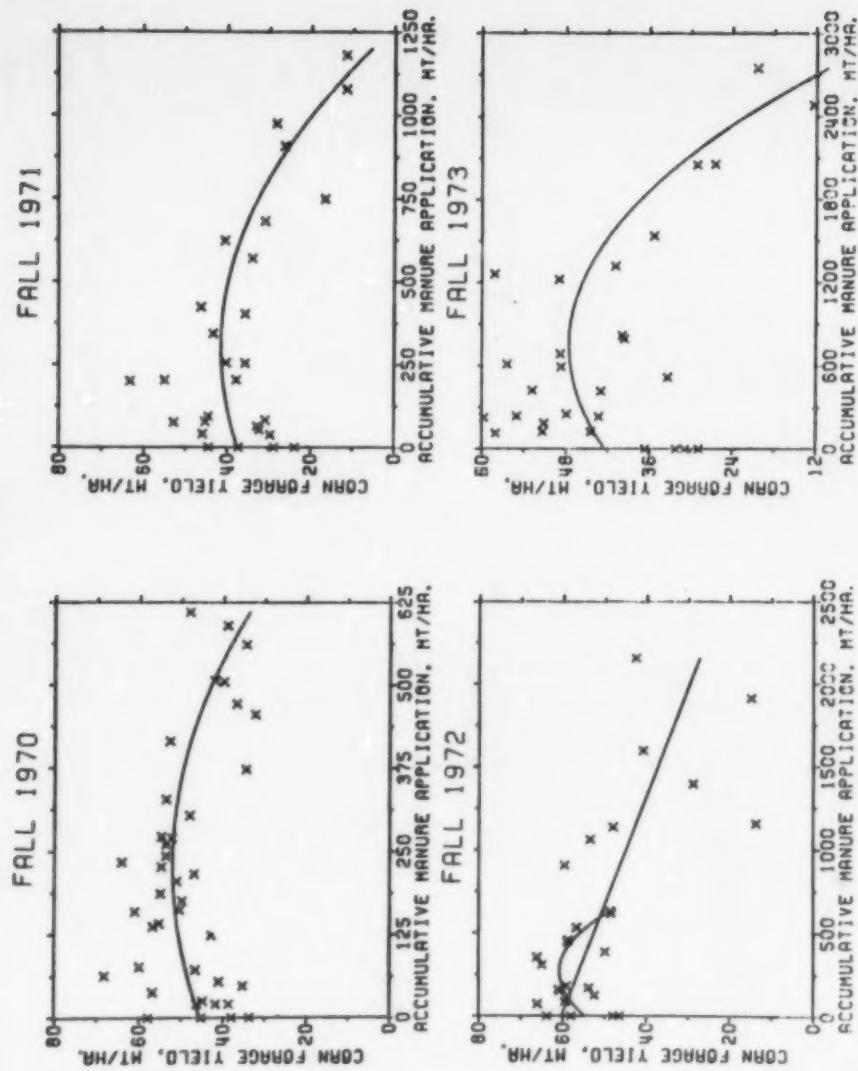


Figure 19. Corn forage yields (corrected to 30% dry matter) as affected by accumulative applications of beef feedlot manure (dry weights) that began in 1969.

per hectare per year (MT/ha./yr) in 1970, 1971, and 1973, respectively. Maximum yields cannot be expected to continue at these rates, however, because saline soil conditions would eventually be created. By inspection of Figures 13 and 19, it can be seen that near maximum yields were recorded from the eight plots receiving the lowest treatments and that significant salt buildup had not occurred at these rates (29 - 68 MT/ha./yr after 4 years) by the spring of 1973. Continued study will be needed to determine if these rates can be maintained without deleterious effects on forage yields.

Uptake of N, P, K, and Ca in 1970 and N and P in 1971 was quadratically related to accumulative treatment as was yield in those years (Figure 20 and Table 12). Mg uptake in 1970 and Ca and Mg uptake in 1972 were linearly depressed by manure treatments. These data show that removal of these elements from the soil can be reduced by heavy applications of manure that reduce corn forage production. Na uptake was not found to be affected by manure treatment.

NO_3^- -N content of corn forage was a quadratic function of treatment in 1971 and 1972 and a linear function in 1973 (Figure 21). In 1972, forage NO_3^- -N concentrations from plots receiving accumulative manure applications of from 124 MT/ha. (41 MT/ha./yr) to 631 MT/ha. (210 MT/ha./yr) generally exceeded 700 ppm NO_3^- -N, a known level at which animal toxicity can occur if ingested (Gardner⁶⁸).

Effects of Residual Treatments on Soil Chemical Properties

EC analysis of surface soil samples taken in the fall of 1972, three years after the manure was applied, showed residual accumulations of soluble salts (Figure 22). The EC values were lower than those measured in 1970 (Figure 13) indicating that leaching and plant uptake had removed much of the salts out of the surface 15 cm. By the spring of 1973 there was little relationship between surface EC and treatment (Table 13).

In the two replications where soil cores were taken, the four plots that were intended to receive the two lower residual treatments received actual tonnages that were so close together that, for practical comparative purposes, they could not be separated. The data presented in Figures 23 and 24 are based on a control and two residual treatments: control, an average of data from two plots; 230 MT/ha., an average from four plots; and 481 MT/ha., an average from two plots. Data from adjacent depth increments were combined in the same manner described for the yearly treatments.

In the fall 1972 cores, no differences between the two residual treatments and the control were found in the extractable Na content at the 10-cm depth (Figure 23). Higher concentrations of Na were found at depths below 10 cm under plots receiving residual manure treatments than under control plots. This indicates that in three years most of the

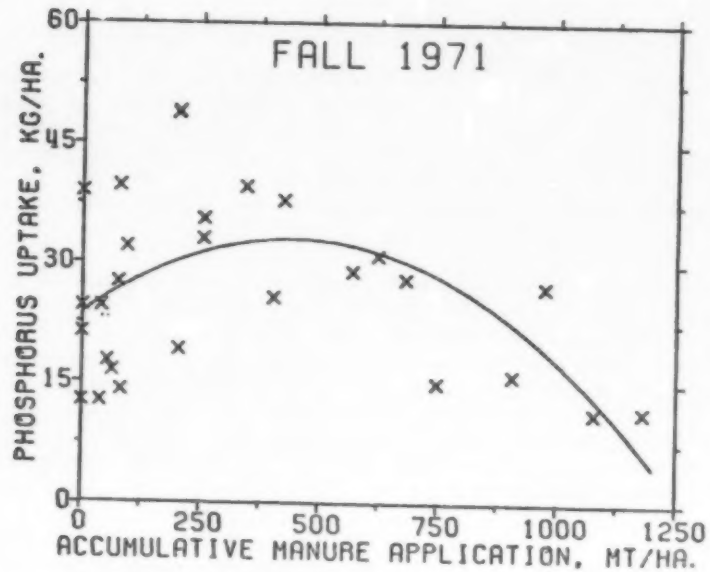
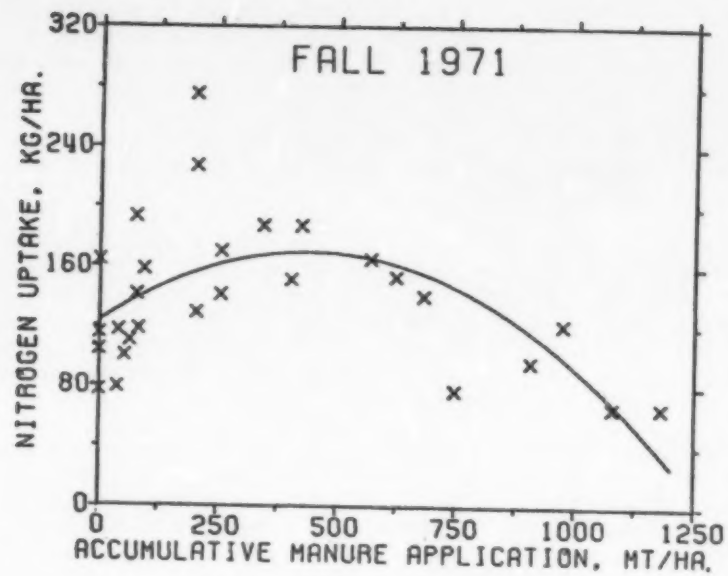


Figure 20. Uptake of N and P by corn forage as affected by accumulative applications of beef feedlot manure (dry weights) that began in 1969.

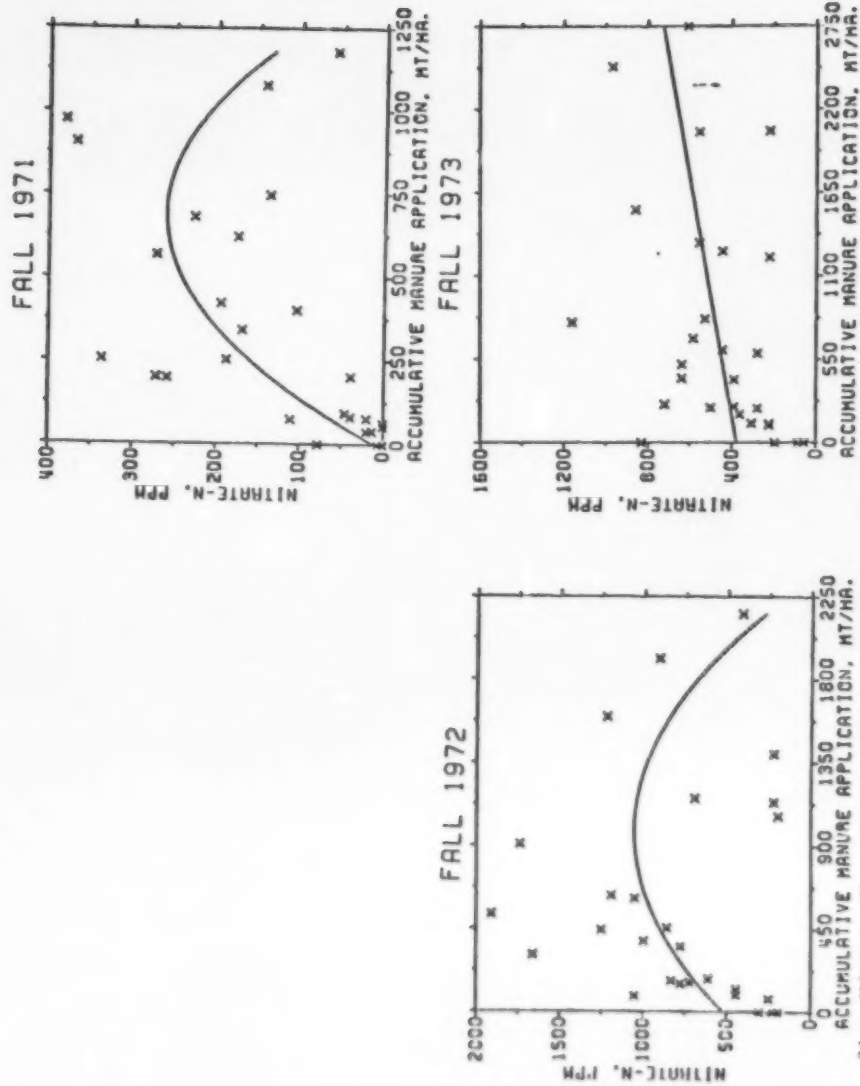


Figure 21. Nitrate-N content of corn forage (dry weight basis) as affected by accumulative applications of beef feedlot manure (dry weights) that began in 1969.

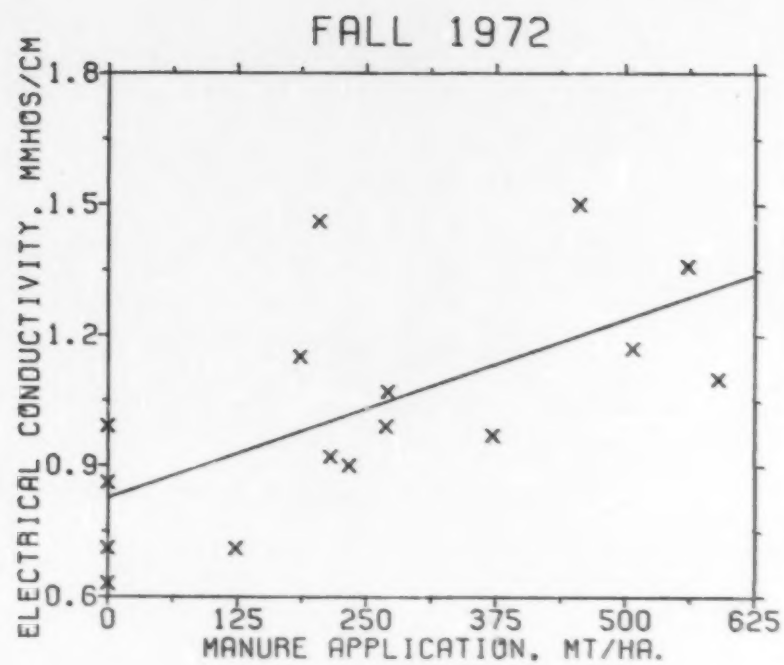


Figure 22. Electrical conductivity of water saturated paste extracts from surface (0 to 15 cm) soil samples as affected by a single application of beef feedlot manure (dry weights) in 1969.

Table 13. CORN FORAGE YIELD, UPTAKE OF INDICATED ELEMENTS, CORN PLANT POPULATION, NITRATE-N CONTENT OF CORN FORAGE, AND ELECTRICAL CONDUCTIVITY OF SURFACE SOIL SATURATION EXTRACTS AS AFFECTED BY A SINGLE APPLICATION OF BEEF FEEDLOT MANURE (DRY MT/ha.) IN THE FALL OF 1969

Measurement	R ²	a ^a	b ^a	c ^a	F
1971					
Yield (MT/ha.)	0.211	-0.0000991	0.0638	34.1	1.74
N uptake (kg/ha.)	0.268	-0.000444	0.350	117.0	2.42
P uptake (kg/ha.)	0.230	-0.0000534	0.0552	23.5	1.97
K uptake (kg/ha.)	0.013	-0.000427	0.216	253.0	0.09
Ca uptake (kg/ha.)	0.109	-0.0000703	0.0458	0.109	0.83
Mg uptake (kg/ha.)	0.239	-0.0000555	0.0343	13.8	2.14
Na uptake (kg/ha.)	0.159	-0.00000789	0.00380	0.814	1.24 ^b
Population (No./ha.)	0.381	---	-6.36 ^b	0.381	8.62 ^b
Fall Soil EC (mmho/cm)	0.365	---	0.00144 ^b	0.819	8.04 ^b
Forage Nitrate-N (ppm)	0.626	---	0.746 ^b	-7.34	23.44 ^b
1972					
Yield (MT/ha.)	0.163	-0.0000561	0.0364	54.8	1.27 ^b
N uptake (kg/ha.)	0.529	-0.0006756	0.475 ^b	136.0	7.30 ^b
P uptake (kg/ha.)	0.543	-0.000135 ^b	0.0970	28.3	7.73 ^b
K uptake (kg/ha.)	0.314	---	0.171 ^b	195.0	6.41 ^b
Ca uptake (kg/ha.)	0.039	0.0000424	-0.0181	27.3	0.26
Mg uptake (kg/ha.)	0.014	---	0.00319	18.4	0.20
Na uptake (kg/ha.)	0.008	---	-0.000117	0.670	0.12
Population (No./ha.)	0.041	---	2.26	56300.0	0.60 ^b
Spring Soil EC (mmho/cm)	0.651	---	0.00169 ^b	0.797	26.17 ^b
Fall Soil EC (mmho/cm)	0.422	---	0.000825 ^b	0.825	10.20 ^b
Forage Nitrate-N (ppm)	0.231	-0.00393	3.61	118.0	1.95

Table 13 (Continued). CORN FORAGE YIELD, UPTAKE OF INDICATED ELEMENTS, CORN PLANT POPULATION, NITRATE-N CONTENT OF CORN FORAGE, AND ELECTRICAL CONDUCTIVITY OF SURFACE SOIL SATURATION EXTRACTS AS AFFECTED BY A SINGLE APPLICATION OF BEEF FEEDLOT MANURE (DRY MT/ha.) IN THE FALL OF 1969

Measurement	R ²	a ^a	b ^a	c ^a	P
1973					
Yield (MT/ha.)	0.686	-0.000106 ^b	0.0947 ^b	32.0	14.19 ^b
Population (No./ha.)	0.011	---	-2.08	44600.0	0.15
Spring Soil EC (mmho/cm)	0.121	---	0.000807	1.04	1.92
Forage Nitrate-N (ppm)	0.147	18.9	-0.871	284.0	1.12

^a Data are expressed as factors of a regression equation: $y = ax^2 + bx + c$.

^b Significant at the 0.05 level.

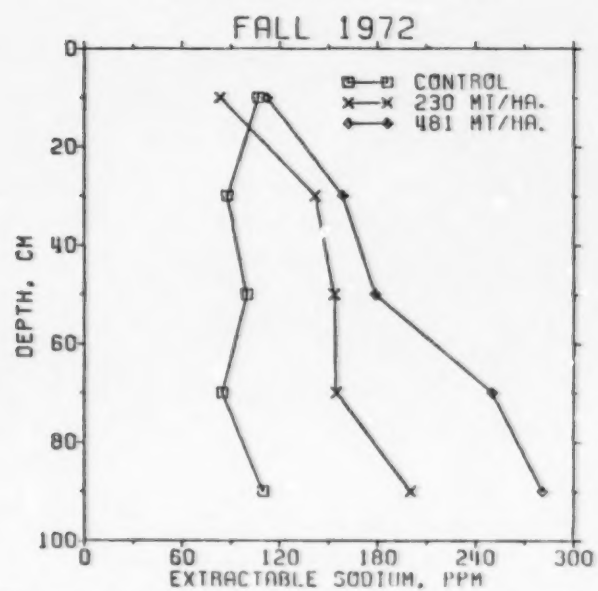
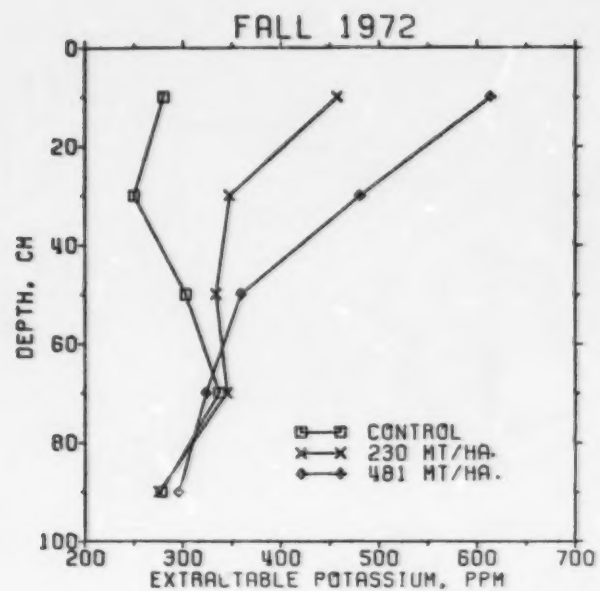


Figure 23. Extractable Na and K content of soil cores as affected by depth and a single application of beef feedlot manure (dry weights) in 1969.

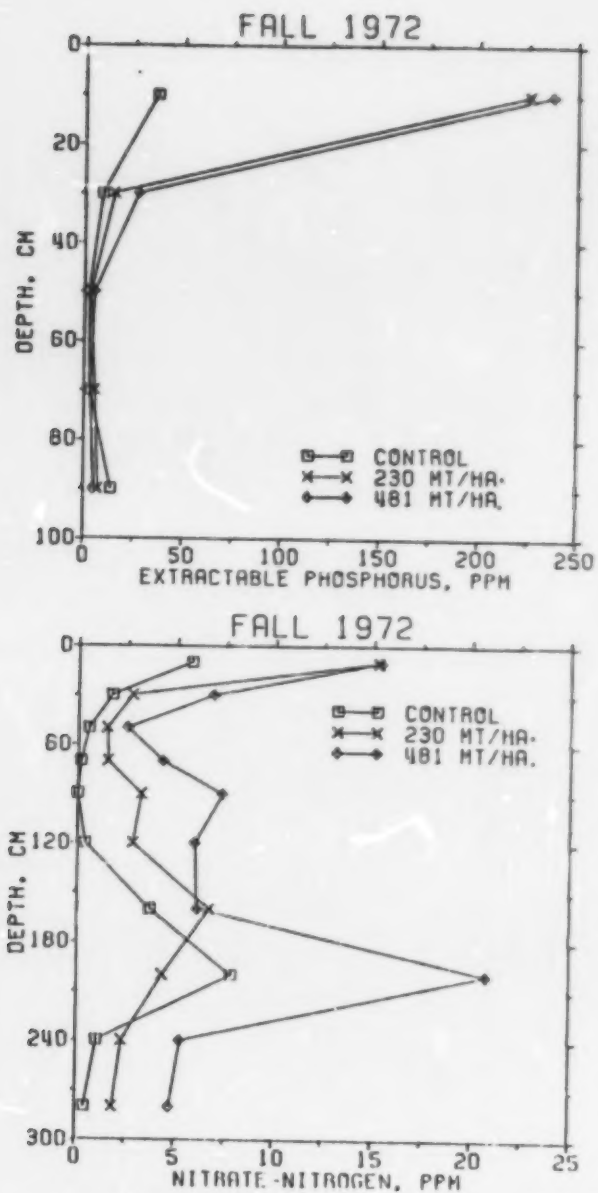


Figure 24. Nitrate-N and extractable P content of soil cores as affected by a single application of beef feedlot manure (dry weights) in 1969.

applied Na had been leached from the surface 20 cm and transported to lower depths with maximum movement of at least one meter. By the fall of 1972, K had showed no movement below the 50-cm depth (Figure 23) and P had no movement below the 30-cm depth (Figure 24). The fall 1972 cores showed increases of NO_3^- -N at the 160-cm depth under plots that had received 230 MT/ha. and at the 200-cm depth under plots that had received 481 MT/ha. (Figure 24). No trend due to treatment could be found in the analysis of soil cores for extractable Ca or Mg.

Effects of Residual Treatments on Corn

Residual positive effects on soil fertility were expressed as increased corn forage yield in 1973, four years after the application of manure (Figure 25). Less consistent quadratic trends were found in the 1971 and 1972 yields (Table 13). A negative effect on corn plant population was still evident in 1971, two years after manure applications, but an effect was not found in 1972 or 1973 indicating that leaching of salts from the surface soil or lowered ammonification had been sufficient by 1972 to prevent germination damage.

The NO_3^- -N concentrations of the 1971 corn forage were increased linearly by residual treatment but were not raised to toxic levels. Increases in NO_3^- -N concentrations in the 1972 and 1973 forage were not consistent with treatment, but potentially toxic levels (747 to 1160 ppm) were found in the 1972 forage from five plots receiving residual treatments.

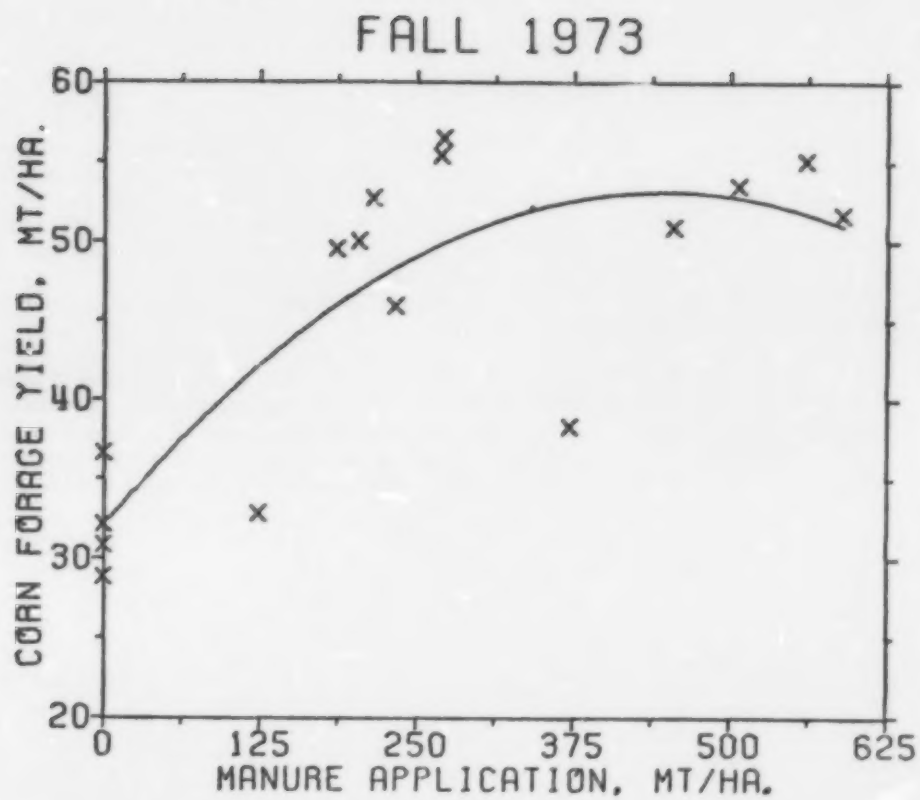


Figure 25. Corn forage yield (corrected to 30% dry matter) four years after a single application of beef feedlot manure (dry weights) in 1969.

SECTION X

MICRONUTRIENT RELATIONSHIPS TO LAND DISPOSAL OF FEEDLOT WASTES

GENERAL

Efficient utilization of plant nutrients contained in animal manures should be an important consideration when disposing of these wastes onto soil. The effects of beef feedlot manure and lagoon water on concentrations of Fe, Zn, Mn, and Cu in corn forage, and on levels of Diethylene Triamine Penta Acetic Acid (DTPA) extractable Fe, Zn, Mn, and Cu in the soil were investigated.

METHODS AND PROCEDURES

The micronutrient study was conducted on selected plots in the waste disposal study area described in Sections VIII and IX of this report. Applied wastes were analyzed for Fe, Zn, Mn, and Cu by atomic absorption techniques after a nitric-perchloric acid digestion.

In the fall of 1971, soil cores were taken by stainless-steel tubing to one meter from three control plots (no waste or chemical fertilizer), 12 plots (representing six treatments) that had received yearly manure applications for two years, six plots (representing two treatments) that received manure application two years previously, and eight plots (representing four treatments) that received two years of lagoon water treatments. These cores were divided into 10-cm increments and analyzed for DTPA-extractable Fe, Zn, Mn, and Cu using the procedure outlined by Lindsay and Norvell.⁶⁹ Atomic absorption techniques were used for the extract analysis. The pH of selected soil cores that had received yearly manure applications was measured using a 1:1 soil water ratio.

Corn forage yield measurements (corrected to 30% dry matter) and corn forage samples were taken in the summers of 1970, 1971, and 1972. Corn leaf samples (June 15 to July 15) were taken in 1970, 1971, and 1972 from plots receiving manure. The plant samples were analyzed by atomic absorption for Fe, Zn, Mn, and Cu after a nitric-perchloric acid digestion.

RESULTS AND DISCUSSION

Waste Analysis and Soil pH

Table 14 gives the average analysis of the manure and lagoon water applied to the disposal plots for total Fe, Zn, Mn, and Cu. Measurements of pH of selected soil cores taken from plots before and after they had received two years of manure applications are given in Table 15. Only very small increases or no change in pH were found, indicating that effects of manure on plant-nutrient availability probably would not be related to alterations of soil pH.

Table 14. AVERAGE ANALYSIS OF BEEF FEEDLOT MANURE AND LAGOON WATER APPLIED TO DISPOSAL PLOTS

	Iron ppm	Zinc ppm	Manganese ppm	Copper ppm
Manure (dry weight basis)				
1969 Average	8820	66.0	---	---
1971 Average	4810	55.6	106	12.8
1972 Average	5810	46.6	192	20.2
Sample High	10300	120.0	234	29.3
Sample Low	3000	35.7	43	10.9
3-Year Average	6480	56.1	149	16.5
Lagoon water (wet weight basis)				
1972 Average	1.8	0.14	0.29	0.51
Sample High	2.2	0.19	0.34	0.55
Sample Low	1.3	0.05	0.25	0.40

Table 15. THE pH (1:1 SOIL TO WATER RATIO) OF SELECTED SOIL CORES

Depth cm	Average accumulative manure treatment (MT/ha.)							
	0		85		372		1040	
Date:	1969	1971	1969	1971	1969	1971	1969	1971
0-10	7.1	7.2	7.0	7.2	7.2	7.3	7.0	7.2
10-20	7.0	7.0	6.4	7.1	7.0	7.3	7.1	7.2
20-30	7.1	7.0	7.0	7.2	7.3	7.4	6.9	6.9
30-40	7.1	7.1	7.2	7.2	7.5	7.5	6.8	7.0
40-50	7.6	7.4	7.3	7.4	7.9	7.6	7.0	7.4

Iron

Increased DTPA-extractable Fe was found as deep as 15 and 25 cm in soil cores taken from plots that had received accumulative yearly manure applications of 595 and 1043 dry MT/ha., respectively, relative to cores from control plots. Lower yearly treatments had little effect on DTPA Fe. The 481 MT/ha. residual manure treatment increased Fe to 15 cm, while the three highest lagoon water treatments increased Fe at the 5-cm depth with erratic response below 15 cm (Figure 26). Based on these data, high rates of manure and, to a lesser extent, lagoon water will increase the availability of Fe as measured by the DTPA extraction. The much lower amounts of total Fe being added through the lagoon water (Table 14) explains the lesser response of lagoon water on DTPA Fe.

Results of regression analyses on Fe uptake and corn leaf and forage content of Fe are given in Tables 16-18. Fe uptake was not affected by either yearly or residual manure treatments, but was increased by lagoon water linearly in 1970 and quadratically (increased uptake at the intermediate rates and relative decline at the higher rates) in 1971 as was forage yield in those years (Table 18). Forage or leaf Fe content was not consistently related to any type of waste treatment.

The levels of DTPA-extractable Fe measured on all plots, including controls, were higher than 0.25 ppm which is considered to be a critical level below which Fe deficiencies might occur (Whitney *et al.*⁷⁰). Even though the three types of waste treatments did increase available Fe concentrations in the soil, there was evidently so much Fe originally present that corn Fe content and uptake were not affected.

Zinc

All yearly manure treatments increased DTPA Zn at the 5-cm depth and the four highest yearly treatments increased Zn at the 15-cm depth relative to control plots. The residual manure and lagoon water treatments increased DTPA Zn at the 5-cm and 15-cm depths (Figure 27). These data show that the availability of Zn as measured by the DTPA extraction was increased by all waste treatments.

The levels of Zn measured in soils of the control plots were close to 0.5 ppm which is considered to be the critical Zn level below which Zn deficiencies are likely to occur (Whitney *et al.*⁷⁰). Increased availability in the soil was reflected in some years by higher Zn concentrations in corn leaf and forage that had received yearly manure applications (Table 16 and Figure 28). Residual manure or lagoon water had no consistent effect on Zn content of corn leaf or forage (Tables 17 and 18), and Zn uptake was not affected by any type of waste treatment (Tables 16-18).

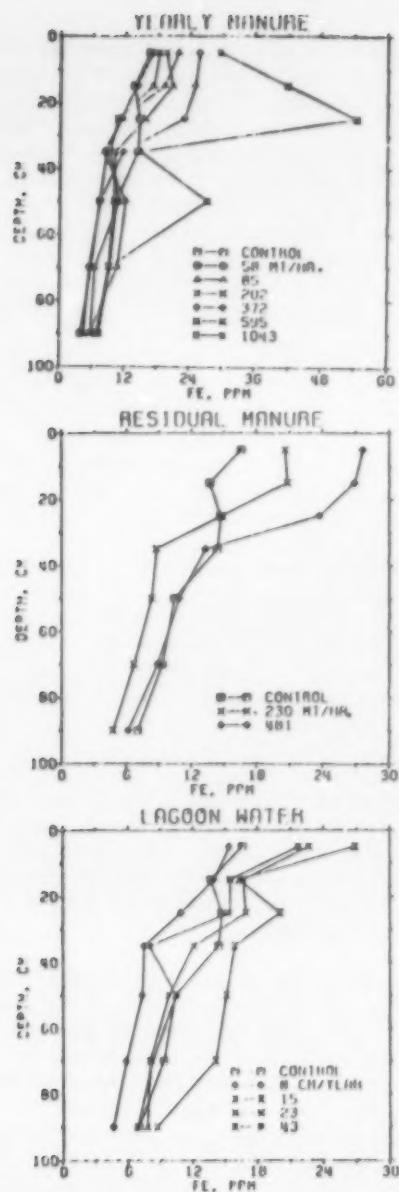


Figure 26. DTPA extractable Fe as affected by depth and applications of beef feedlot wastes.

Table 16. CORN FORAGE YIELD, COMPOSITION AND UPTAKE OF INDICATED ELEMENTS AND CORN LEAF TISSUE COMPOSITION AS AFFECTED BY ACCUMULATIVE YEARLY APPLICATIONS OF BEEF FEEDLOT MANURE (DRY MT/ha.) THAT BEGAN IN THE FALL OF 1969

	R ²	a ^a	b ^a	c ^a	P
1970					
Forage yield (MT/ha.)	0.248	-0.000127 ^b	0.0583 ^b	45.4	6.10 ^b
Forage composition					
Fe (ppm)	0.027	-0.000121	0.0831	113.0	0.51
Zn (ppm)	0.011	0.0000229	-0.0108 ^b	20.3	0.20 ^b
Mn (ppm)	0.524	---	0.0967 ^b	27.5	41.90 ^b
Cu (ppm)	0.020	---	0.00164	6.75	0.41
Forage uptake					
Fe (kg/ha.)	0.102	-0.00000564 ^b	0.00287	1.57	2.53
Zn (kg/ha.)	0.017	-0.000000597	0.000307	0.266	0.32
Mn (kg/ha.)	0.496	---	0.00103 ^b	0.448	37.42 ^b
Cu (kg/ha.)	0.062	-0.000000274	0.000145	0.0922	1.22
Tissue composition					
Fe (ppm)	0.260	---	0.0939 ^b	119.0	13.35 ^b
Zn (ppm)	0.216	---	0.0180 ^b	22.8	10.44 ^b
Mn (ppm)	0.732	---	0.152 ^b	43.9	103.67 ^b
Cu (ppm)	0.018	-0.00000060	0.00369	8.76	0.33
1971					
Forage yield (MT/ha.)	0.491	-0.0000446 ^b	0.0268	37.5	12.06 ^b
Forage composition					
Fe (ppm)	0.065	---	0.0175	95.7	0.87 ^b
Zn (ppm)	0.497	0.0000158 ^b	-0.00854	17.5	12.36 ^b
Mn (ppm)	0.551	---	0.0289 ^b	33.5	31.93 ^b
Cu (ppm)	---	---	---	---	---

Table 16 (Continued). CORN FORAGE YIELD, COMPOSITION AND UPTAKE
OF INDICATED ELEMENTS AND CORN LEAF TISSUE COMPOSITION AS AFFECTED BY ACCUMULATIVE
YEARLY APPLICATIONS OF BEEF FEEDLOT MANURE (DRY MT/ha.) THAT BEGAN IN THE FALL OF 1969

	R^2	a^a	b^a	c^a	r
Forage uptake					
Fe (kg/ha.)	0.243	-0.00000154	0.00112	1.09	4.00 ^b
Zn (kg/ha.)	0.175	-0.00000014 ^b	0.0000900	0.192	2.64 ^b
Mn (kg/ha.)	0.396	-0.00000100	0.000993 ^b	0.349	8.24 ^b
Cu (kg/ha.)	---	---	---	---	---
Tissue composition					
Fe (ppm)	0.003	---	-0.00366	111.0	0.07
Zn (ppm)	0.084	---	0.00433	20.6	2.39 ^b
Mn (ppm)	0.621	-0.0000389 ^b	0.0875 ^b	34.6	20.45 ^b
Cu (ppm)	0.239	---	-0.00305 ^b	8.24	8.18 ^b
1972					
Forage yield (MT/ha.)					
Forage composition	0.480	---	-0.0153 ^b	60.2	24.03 ^b
Fe (ppm)	0.195	0.0000400	-0.0481 ^b	125.0	3.03 ^b
Zn (ppm)	0.207	---	0.00865 ^b	21.4	6.79 ^b
Mn (ppm)	0.472	---	0.0158 ^b	20.0	23.30 ^b
Cu (ppm)	0.097	---	0.00217	4.45	2.80
Forage uptake					
Fe (kg/ha.)	0.056	---	-0.000335	2.07	1.55
Zn (kg/ha.)	0.010	---	-0.0000324	0.411	0.26
Mn (kg/ha.)	0.040	---	0.000165	0.367	0.53
Cu (kg/ha.)	0.005	-0.0000000686	-0.00000741	0.0820	0.13
Tissue composition					
Fe (ppm)	0.047	---	0.00969	108.0	1.29 ^b
Zn (ppm)	0.566	---	0.00729 ^b	29.3	33.85 ^b
Mn (ppm)	0.608	---	0.0163 ^b	36.0	40.30 ^b
Cu (ppm)	0.139	0.00000152	-0.00312	9.02	2.01

^a Data are expressed in the form of a regression equation: $y = ax^2 + bx + c$
^b Significant at the 0.05 level.

Table 17. CORN FORAGE YIELD, COMPOSITION AND UPTAKE OF INDICATED ELEMENTS AND CORN LEAF TISSUE COMPOSITION AS AFFECTED BY A SINGLE APPLICATION OF BEEF FEEDLOT MANURE (DRY MT/ha.) IN THE FALL OF 1969

	R ²	a ^a	b ^a	c ^a	F
1971					
Forage yield (MT/ha.)	0.211	-0.0000991	0.0638	34.1	1.74
Forage composition					
Fe (ppm)	0.010	-0.0000364	0.0243 ^b	94.4	0.07
Zn (ppm)	0.393	---	-0.00823 ^b	18.5	9.07 ^a
Mn (ppm)	0.306	---	-0.0163 ^b	31.8	6.16 ^a
Cu (ppm)	---	---	---	---	---
Forage uptake					
Fe (kg/ha.)	0.132	-0.00000347	0.00226	0.965	1.02
Zn (kg/ha.)	0.090	-0.00000038	0.000163	0.195	0.63
Mn (kg/ha.)	0.224	-0.00000084	0.000755	0.332	1.92
Cu (kg/ha.)	---	---	---	---	---
Tissue composition					
Fe (ppm)	0.041	---	0.0168	95.4	0.60
Zn (ppm)	0.341	0.000125 ^b	-0.0575	23.0	3.37 ^b
Mn (ppm)	0.485	---	0.0253 ^a	33.2	13.20 ^b
Cu (ppm)	0.394	-0.0000271 ^b	0.0186 ^a	5.85	4.23 ^b
1972					
Forage yield (MT/ha.)	0.163	-0.0000561	0.0364	54.8	1.27
Forage composition					
Fe (ppm)	0.325	0.000416 ^a	-0.250 ^a	130.0	3.12
Zn (ppm)	0.039	0.0000334	-0.0145	19.2	0.26
Mn (ppm)	0.065	---	0.00775	19.0	0.98
Cu (ppm)	0.083	-0.0000244	0.0128	5.28	0.59

Table 17 (Continued). CORN FORAGE YIELD, COMPOSITION AND UPTAKE
OF INDICATED ELEMENTS AND CORN LEAF TISSUE COMPOSITION AS AFFECTED
BY A SINGLE APPLICATION OF BEEF FEEDLOT MANURE (DRY MT/ha.) IN THE FALL OF 1969

	R ²	a ^a	b ^a	c ^a	F
1972 (Continued)					
Forage uptake					
Fe (kg/ha.)	0.147	0.00000572	-0.00338	2.19	1.12
Zn (kg/ha.)	0.019	---	0.0000987	0.310	0.27
Mn (kg/ha.)	0.058	---	0.000158	0.330	0.87
Cu (kg/ha.)	0.122	-0.000000550	0.000303	0.0855	0.90
Tissue composition					
Fe (ppm)	0.267	-0.000139	0.108	92.4	2.37
Zn (ppm)	0.334	0.0000491	-0.0347 ^b	31.8	3.27
Mn (ppm)	0.039	-0.0000176	0.00854	35.3	0.26 ^b
Cu (ppm)	0.443	0.0000181	-0.0157 ^b	10.1	5.16 ^b

^a Data are expressed in the form of a regression equation: $y = ax^2 + bx + c$

^b Significant at the 0.05 level.

Table 18. CORN FORAGE YIELD, COMPOSITION AND UPTAKE OF INDICATED ELEMENTS AS AFFECTED BY ACCUMULATIVE YEARLY APPLICATIONS OF BEEF FEEDLOT LAGOON WATER (cm) THAT BEGAN IN THE SUMMER OF 1970

	R ²	a ^a	b ^a	c ^a	F
1970					
Forage yield (MT/ha.)	0.316	---	0.498 ^b	41.5	8.30 ^b
Forage composition					
Fe (ppm)	0.019	---	-0.314	141.0	0.35
Zn (ppm)	0.095	-0.0367	1.22	22.8	---
Mn (ppm)	0.003	---	-0.0381	33.1	0.06
Cu (ppm)	0.092	---	-0.0195	4.52	1.81
Forage uptake					
Fe (kg/ha.)	0.283	---	0.0161 ^b	1.70	7.11 ^b
Zn (kg/ha.)	0.080	-0.000581	0.0228	0.282	---
Mn (kg/ha.)	0.060	---	0.00339 ^b	0.432	1.15 ^b
Cu (kg/ha.)	0.453	---	0.000949 ^b	0.0561	14.89 ^b
1971					
Forage yield (MT/ha.)	0.372	-0.00410 ^b	0.425 ^b	36.3	5.04 ^b
Forage composition					
Fe (ppm)	0.365	-0.00634	0.993 ^b	69.8	4.88 ^b
Zn (ppm)	0.107	0.000521	-0.0372	16.7	1.02 ^b
Mn (ppm)	0.444	---	0.171 ^b	33.2	14.36 ^b
Cu (ppm)	0.528	-0.000487	0.0791	3.61	9.50 ^b
Forage uptake					
Fe (kg/ha.)	0.453	-0.000178 ^b	0.0219 ^b	0.759	9.95 ^b
Zn (kg/ha.)	0.116	-0.0000130	0.00145	0.184	1.75 ^b
Mn (kg/ha.)	0.218	---	0.00205 ^b	0.426	7.14 ^b
Cu (kg/ha.)	0.425	-0.0000109 ^b	0.00141 ^b	0.0424	8.54 ^b

Table 18 (Continued). CORN FORAGE YIELD, COMPOSITION AND
UPTAKE OF INDICATED ELEMENTS AS AFFECTED BY ACCUMULATIVE YEARLY
APPLICATIONS OF BEEF FEEDLOT LAGOON WATER (cm) THAT BEGAN IN THE SUMMER OF 1970

	R^2	a^a	b^a	c^a	F
		1972			
Forage yield (MT/ha.)	0.269	-0.00322 ^b	0.426 ^b	49.2	3.13
Forage composition					
Fe (ppm)	0.015	---	0.112	157.0	0.28
Zn (ppm)	0.176	---	-0.0256	19.0	3.84 ^b
Mn (ppm)	0.489	---	0.123 ^b	28.3	17.22 ^b
Cu (ppm)	0.223	-0.000448	0.0667	3.96	2.44
Forage uptake					
Fe (kg/ha.)	0.156	-0.000164	0.0237	2.27	1.60
Zn (kg/ha.)	0.162	-0.0000153	0.00163 ^b	0.285	1.64 ^b
Mn (kg/ha.)	0.486	-0.0000389 ^b	0.00713 ^b	0.399	8.04 ^b
Cu (kg/ha.)	0.305	-0.0000121 ^b	0.00171 ^b	0.0600	3.73 ⁿ

^a Data are expressed in the form of a regression equation: $y = ax^2 + bx + c$

^b Significant at the 0.05 level.

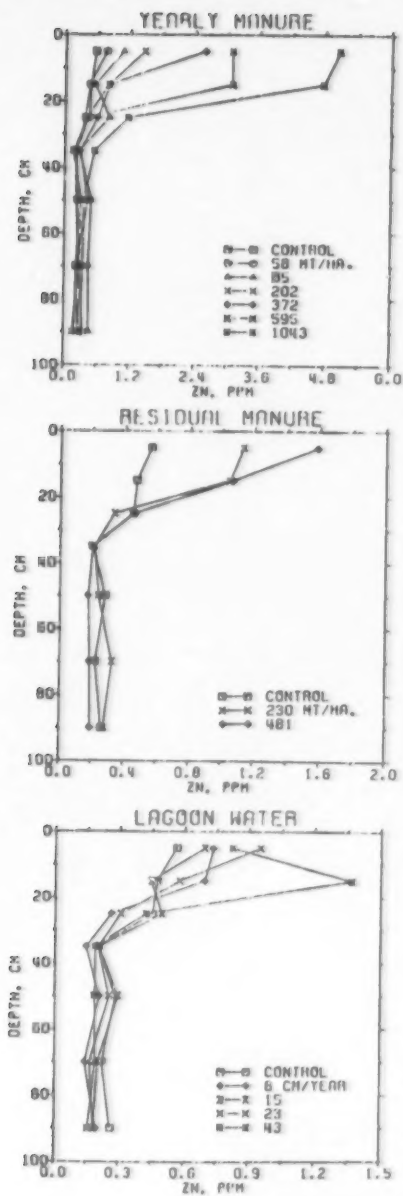


Figure 27. DTPA extractable Zn as affected by depth and applications of beef feedlot wastes.

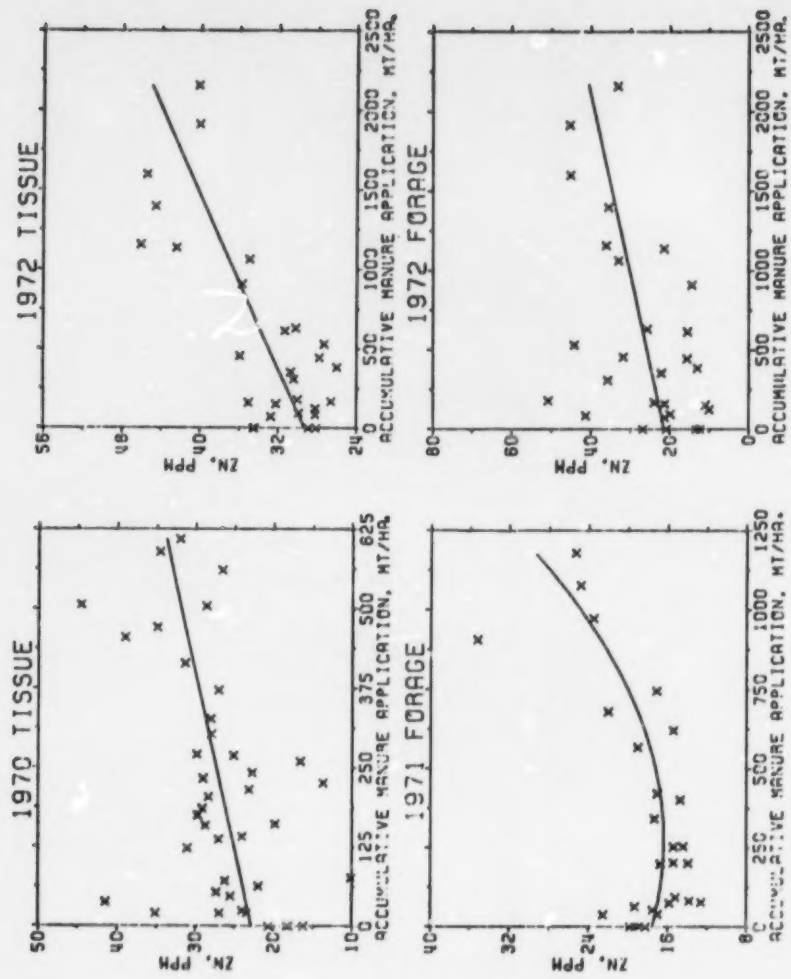


Figure 28. Zinc concentrations in corn leaf tissue and corn forage as affected by accumulative yearly applications of beef feedlot manure (dry weights) that began in 1969.

Manganese

DTPA-extractable Mn was found to be at high concentrations at depths of from 15 to 50 cm under plots receiving the highest yearly manure treatment but this trend was not present in plots receiving the second highest yearly manure treatment (Figure 29). Increased DTPA Mn was found, relative to control plots, at the 15- and 25-cm depths in cores taken from plots receiving all yearly manure treatments except the lowest and the second highest. Residual manure treatments had little effect on DTPA Mn, while all lagoon-water treatments increased Mn at the 5-cm depth (Figure 29). These data show that applications of beef feedlot wastes can increase DTPA-extractable Mn in soil.

Manganese content in corn was more correlated to waste treatment than any of the four elements measured. Forage and leaf content of Mn was increased at all sampling dates by the yearly manure treatments (Figure 30 and Table 16). Residual manure treatments caused inconsistent response in corn Mn content: 1971 forage Mn content was linearly depressed by treatment while 1971 leaf content was linearly increased (Table 17). Lagoon-water treatments linearly increased Mn in the 1971 and 1972 corn forage (Figure 31 and Table 18). Increased forage Mn content masked relative yield depression by the higher yearly manure treatments in 1970 and by the higher lagoon-water treatments in 1971, which resulted in linear Mn uptake response in these years when the yield response was quadratic. Mn uptake did, however, have similar quadratic responses as those of yield in 1971 from plots receiving yearly manure and in 1972 from plots receiving lagoon water (Figures 32 and 33 and Tables 16 and 18).

The DTPA Mn data and, to a greater extent, the plant Mn data show that manure and lagoon water increased the availability of Mn in the soil. In other work (Hensler *et al.*^{46,47} Atkinson *et al.*⁴⁸ Page⁵⁴), Mn became less available when manure was applied; the lowered availability was attributed to a liming effect of the manure which raised soil pH and lowered the solubility of Mn compounds. Inorganic Mn equilibria has been reviewed by Lindsay.²⁹ Since the soil in this study was neutral to basic before manure applications and pH was not appreciably raised by the manure, a factor other than pH must have influenced Mn availability. This factor could have been the creation of reducing conditions in the soil during and after irrigations when waterlogged soil conditions along with organic matter decomposition would lower the oxygen supply and EC. Meek *et al.*⁷¹ found increased Mn and Fe in soil solutions when an organic-matter-amended calcareous soil was flooded. Soils conditions similar to those measured by Meek *et al.*⁷¹ would probably have been created in this study by feedlot waste applications and irrigations with the resultant increase of the reduced Mn^{+2} form in solution.

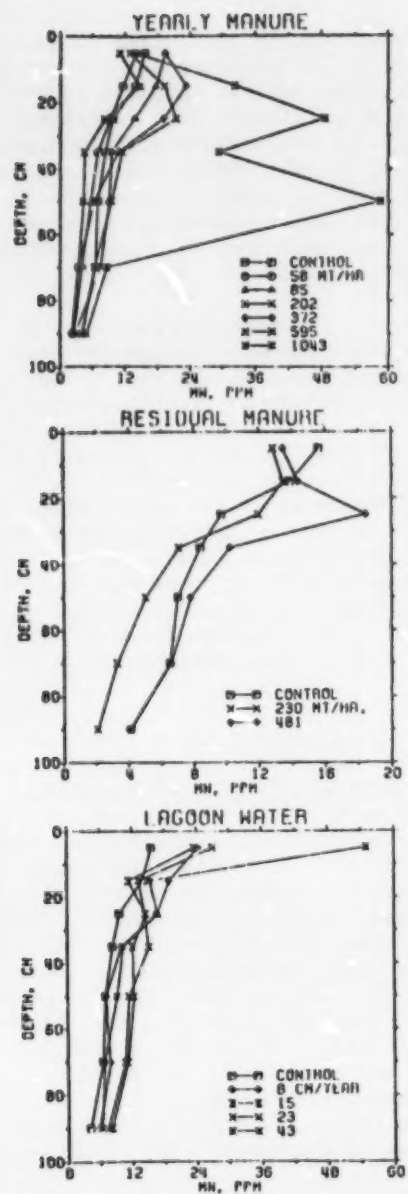


Figure 29. DTPA extractable Mn as affected by depth and applications of beef feedlot wastes.

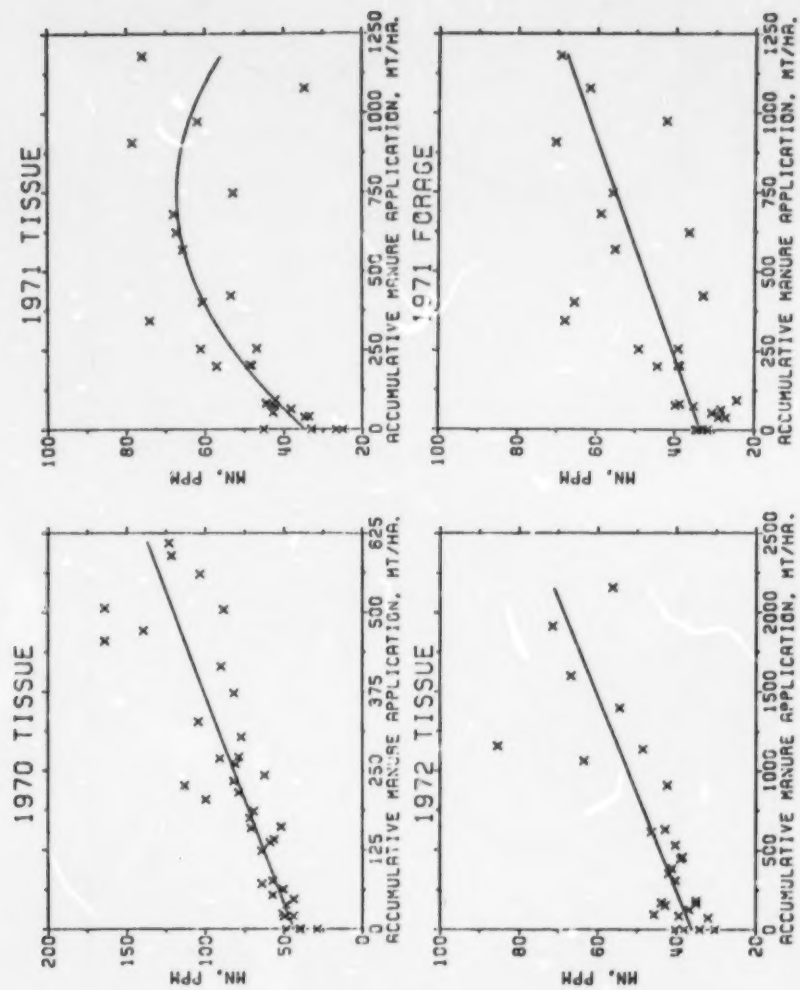


Figure 30. Manganese concentrations in corn leaf tissue and corn forage as affected by accumulative yearly applications of beef feedlot manure (dry weights) that began in 1969.

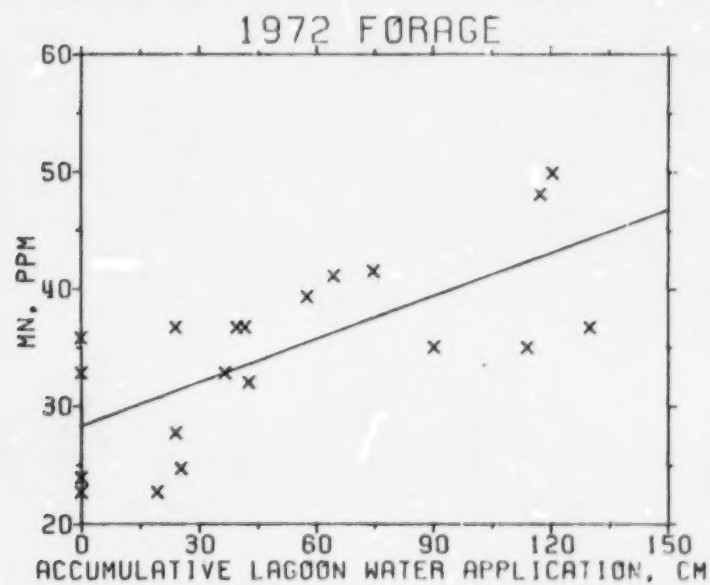
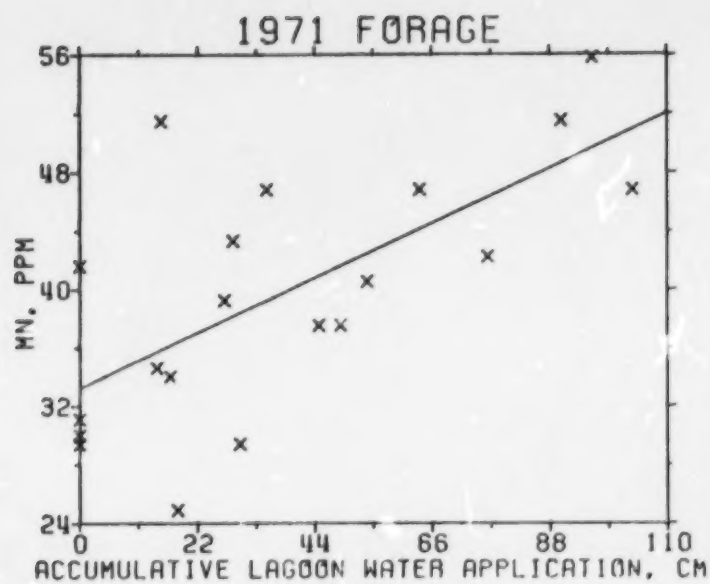


Figure 31. Manganese concentrations in corn forage as affected by accumulative yearly applications of beef feedlot lagoon water that began in 1970.

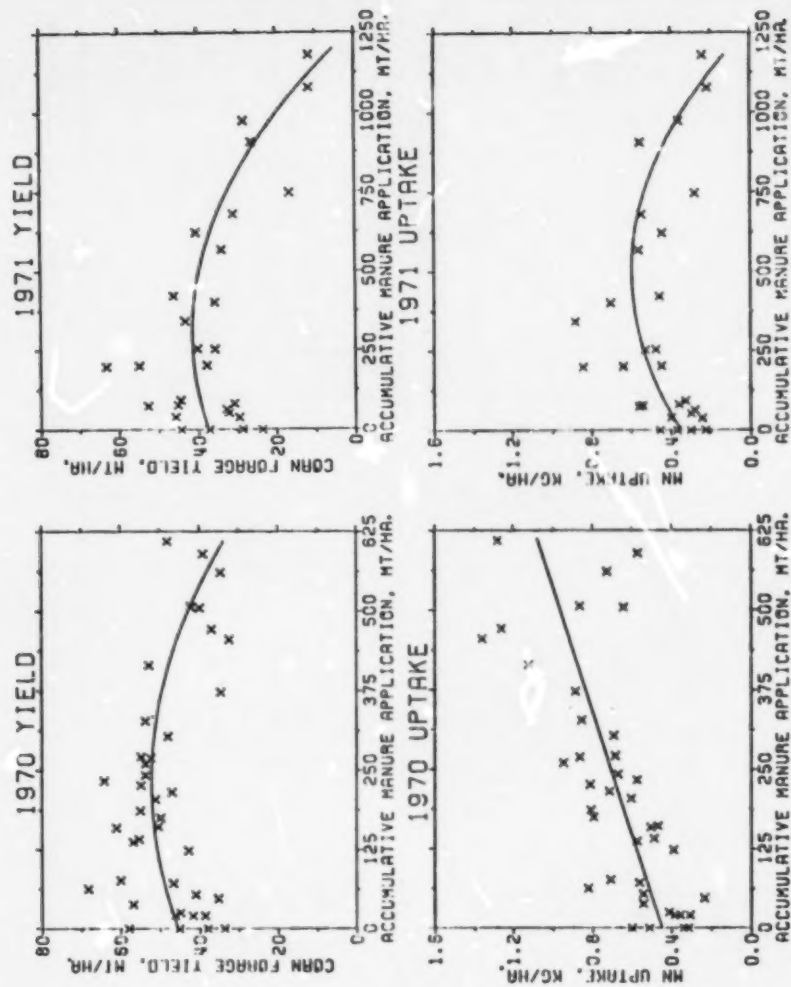


Figure 32. Corn forage yield and manganese uptake as affected by accumulative yearly applications of beef feedlot manure (dry weights) that began in 1969.

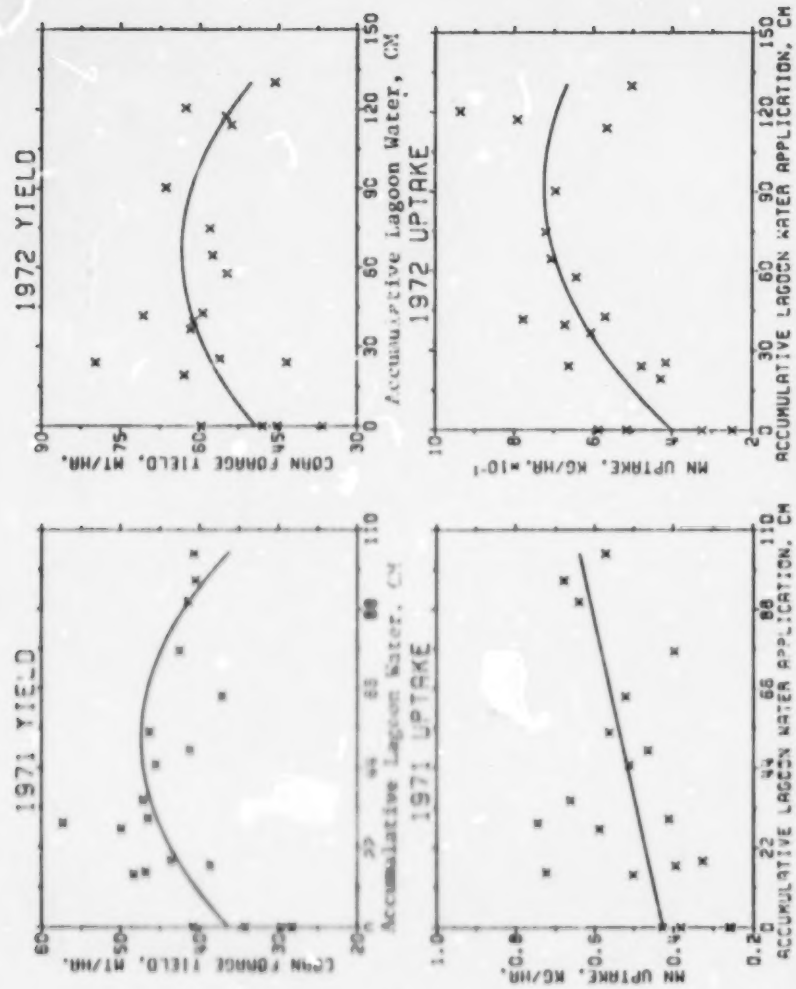


Figure 33. Corn forage yield and manganese uptake as affected by accumulative yearly applications of beef feedlot lagoon water that began in 1970.

Copper

The two highest yearly manure treatments were the only feedlot waste treatments which increased DTPA-extractable Cu. Cores from plots receiving the residual manure and lagoon water treatments had levels of DTPA Cu that were either similar to or lower than levels measured in control plot cores (Figure 34).

Copper uptake by corn forage and Cu content in corn forage was not affected by the yearly or residual manure treatments. A linear decrease in Cu content of corn leaf tissue occurred in 1971, the only year that yearly manure treatments influenced this measurement. Corn leaf content of Cu had opposite quadratic effects due to residual manure treatment in 1971 and 1972: in 1971 Cu content was maximized by the intermediate residual treatments, while in 1972 these same treatments minimized Cu content in corn leaves. An explanation for these opposing trends is not obvious. Uptake of Cu by corn forage grown on plots receiving the lagoon water treatments followed trends that were similar to yield trends: linear increase in 1970 and quadratic (maximization at the intermediate rates) in 1971 and 1972. A quadratic trend in Cu content of corn forage due to lagoon water was found in 1971 only (Table 18).

The soil and plant Cu data showed little consistent response to application of beef feedlot wastes.

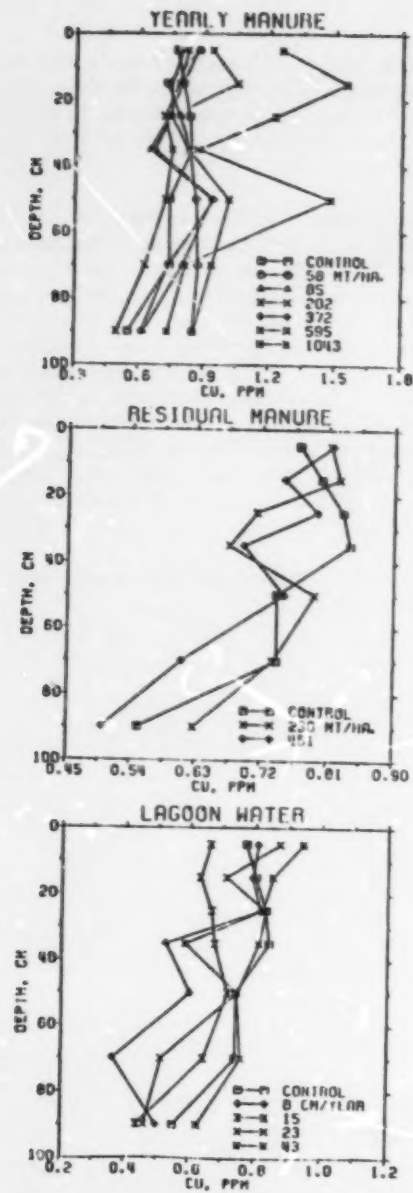


Figure 34. DTPA extractable Cu as affected by depth and applications of beef feedlot wastes.

SECTION XI

DENITRIFICATION STUDY

GENERAL

Since denitrification could be significantly affecting the N balance of the neutral to basic soil on the manure disposal plots, four plots were selected for more detailed study in the summers of 1972 and 1973. In these plots, soil chemical and atmospheric conditions that affect denitrification or suggest its presence were measured.

METHODS AND PROCEDURES

The denitrification study was conducted on four plots in the manure disposal study area which has been described in Section IX of this report. By the summer of 1973, the average annual treatments were 0, 58, 306, and 687 MT/ha. of dry manure.

Soil cores collected to a depth of three meters in the fall of 1969 before manure applications and in the fall of 1971 after two years of treatments were analyzed in 10-cm increments for total N to one meter (not to include NO_3^- -N) by micro-kjeldahl digestion with sulfuric acid and subsequent steam distillation (Keeney and Bremner⁶⁷) and for NO_3^- -N to three meters by steam distillation. One-meter soil cores taken in the fall of 1970 and 1972 after one and three manure applications, respectively, were analyzed in 10-cm increments for organic C using a LECO 70-Second Analyzer (Belo⁷² and Tabatabai and Bremner⁷³) to obtain C and subtracting the carbonate-C obtained by acid neutralization (Black⁷⁴).

Soil-atmosphere-access tubes were installed in mid-July of 1972 and 1973 at seven depths (5-10, 10-20, 20-30, 30-40, 40-60, 60-80, and 80-100 cm), each depth being replicated four times in each plot. The tubes were built and installed so that the gas within the tube would come to equilibrium with the gas in the soil depth being sampled (Figure 35). In early September of 1972 and 1973, 10-ml gas samples were removed by syringe from the tubes and transferred to 15-ml glass bottles that had been evacuated by a hand vacuum pump to 38.1 cm of mercury. The samples were analyzed for N_2 , O_2 , CO_2 , CH_4 , and N_2O using a Carle Model 8000 gas chromatograph with Porapak-Q (first) and molecular sieve (second) columns installed in series. Flow rate was 25 milliliters per minute

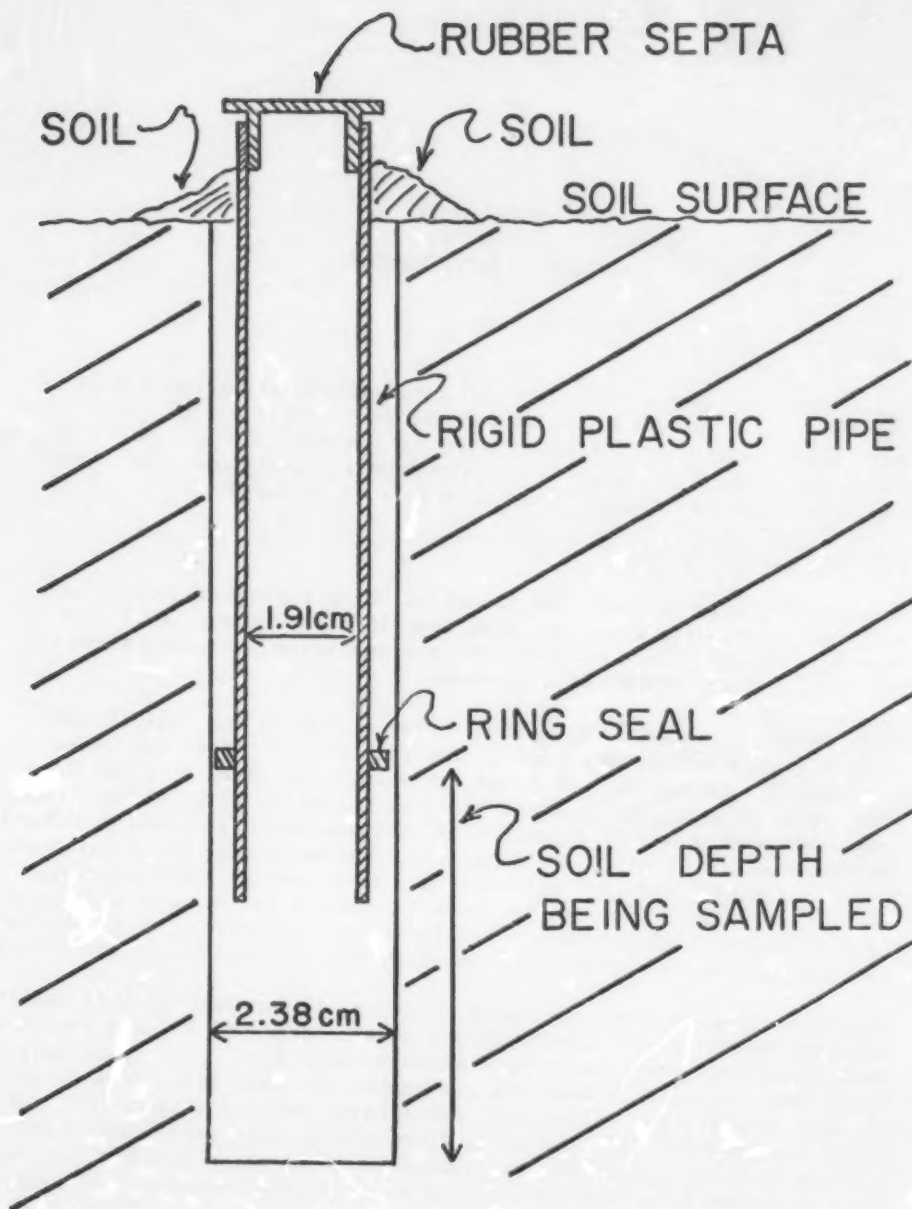


Figure 35. Soil-atmosphere-access tube design.

(ml/min) and oven temperature was 55° C. It was assumed that no gases other than the above five would be present in significant quantities. Area normalization with correction factors for the relative sensitivity of the machine for each gas was used for calculation of percentage composition (McNair and Bonelli⁷⁵). The time between collection and analysis was approximately six months for the 1972 samples and one month for the 1973 samples.

In 1972, one-meter soil cores were taken in May, June, July, and September at four locations in each of the four plots. The May sampling was made approximately two weeks after planting and the later samplings were made from 7-14 days after 10-cm irrigations. The cores were divided into seven depth increments, stored in plastic bags, and frozen in the field with dry ice. After crushing the frozen soil samples to obtain a representative sample, the soil was analyzed for $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ by steam distillation (Keeney and Bremner⁶⁷), for $\text{NO}_2^-\text{-N}$ by the Greiss-Ilosvay method (Black⁷⁴), and for gravimetric water. In 1973, soil solution samples were obtained by porous cups at six depths to one meter at four locations in each plot. Vacuum was applied to the cups on August 10, one day after a 10-cm irrigation, and on August 24, one day after an 8-cm rain. Vacuum was maintained until water samples were collected the next day and refrigerated. The solution samples were analyzed for $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ by steam distillation (Keeney and Bremner⁶⁷), for $\text{NO}_2^-\text{-N}$ by the Greiss-Ilosvay method (Black⁷⁴), and, after filtering, for Fe and Mn by atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

Total Nitrogen and Organic Carbon

Nitrogen balance calculations based on the total N and $\text{NO}_3^-\text{-N}$ analysis of the fall 1970 and 1971 soil cores are given in Table 19. It can be seen that significant amounts of N cannot be accounted for by the measurements used. The plots receiving the two lowest manure treatments lost more nitrogen from the fall of 1969 to the fall of 1971 than was added in the manure during that period, indicating that the manure had caused disappearance of native N. Of the plots receiving manure, the ones receiving the heaviest manure treatments had the least amount of unaccountable N. In work we reported earlier (Murphy *et al.*⁷⁶), soluble salt accumulations in the soil were thought to be responsible for the decreased growth of corn by increasing the osmotic potential of the soil solution. This negative growth factor could have similarly affected the functioning of denitrifying organisms and lowered net N loss from plots receiving the large tonnages of manure.

Total N concentrations in the 1971 soil cores increased to a depth of 50 cm under plots receiving 522 MT/ha./yr and increased to a depth of 10 cm under plots receiving 298 MT/ha./yr (Figure 36). The lower treatments did not appreciably change total N content at any depth.

Table 19. NITROGEN BALANCE CALCULATIONS IN PLOTS THAT
HAD RECEIVED APPLICATIONS OF BEEF FEEDLOT MANURE (DRY MT/ha.)

	Accumulative manure applied					11T/ha.
	Control ^f	58 ^g	85 ^g	202 ^g	372 ^g	
Fall 1969						
Average kjeldahl % N-1m depth ^c	0.0658	0.0858	0.0964	0.0823	0.0681	0.0763
kg in 1 ha.-m ^a	9212.0	12010.0	13500.0	11520.0	9530.0	10680.0
Average ppm NO ₃ -N - 3m depth	1.0	1.5	2.0	1.7	2.3	1.5
kg in 3 ha.-m ^a	42.0	63.0	84.0	71.0	97.0	63.0
Total N - kg/ha. ^b	9250.0	12070.0	13580.0	11590.0	9630.0	10740.0
Fall 1971						
Average kjeldahl % N-1m depth ^c	0.0633	0.0746	0.0795	0.0781	0.0749	0.1417
kg in 1 ha.-m ^a	8860.0	10440.0	11130.0	10930.0	10490.0	19840.0
Average ppm NO ₃ -N - 3m depth	1.1	1.9	2.8	6.7	7.0	9.5
kg in 3 ha.-m ^a	8910.0	10520.0	11250.0	11210.0	10780.0	20240.0
Total N difference - kg/ha. ^d	-340.0	-1550.0	-2330.0	-380.0	+1150.0	+9500.0
N added in manure - kg/ha.	0.0	580.0	850.0	2020.0	3720.0	10430.0
N removed by corn - kg/ha.	204.0	200.0	353.0	384.0	358.0	364.0
Unaccounted for N ^e	136.0	1930.0	2830.0	2020.0	2210.0	1740.0

^a The bulk density of the soil was 1.4 g/cm³.

^b It was assumed that there was no change in kjeldahl N below 1 m.

^c The soil samples were contaminated with NH₄-N during cold storage. To correct for this contamination, steam distillable NH₄-N was subtracted from the kjeldahl N and the difference reported here.

^d Total N in 1971 minus total N in 1969.

^e Unaccounted for N = N added in manure - N removed by corn - Total N difference.

^f Data from one control plot.

^g Average of two plots.

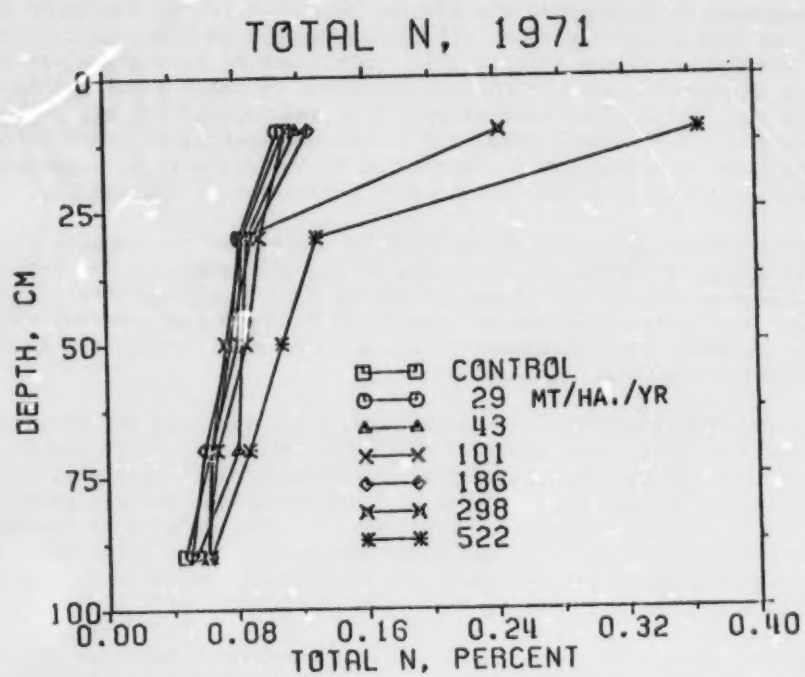


Figure 36. Total N (dry weight basis) in soil cores as affected by depth and two years of beef feedlot manure applications.

Organic carbon increased relative to the control at the 10-cm depth in all three manured plots in 1970 and 1972 (Figure 37). Movement of C to the 50-cm depth was evident in the 1972 soil sampling from the plot that received 687 MT/ha./yr. Some of this increased C would be available for oxidation in denitrification reactions.

Soil Atmosphere

Analyses for N_2 , O_2 , CO_2 , CH_4 , and N_2O in the atmospheric samples taken in late summer of 1972 and 1973 were averaged over the four replications at each depth and are presented in Figures 38-41. No trend due to treatment is evident in the 1972 N_2 data, but the 1973 data do show lower percentages of N_2 at all depths beneath the plot that received 687 MT/ha./yr of manure (Figure 38). This lower N_2 percentage was probably due to higher levels of CO_2 and CH_4 found in these samples (Figures 40 and 41), which would have displaced N_2 and lowered its relative concentration. Increased levels of N_2 would be expected if denitrification had been occurring, but production of N_2 by denitrifying organisms could have been overshadowed by increased production of CO_2 and CH_4 .

Lower percentages of O_2 were found at several depths beneath the plots receiving 687 MT/ha./yr of manure at the 1972 sampling and beneath plots receiving 306 and 687 MT/ha./yr at the 1973 sampling. Lower O_2 percentages could have been due to removal of O_2 for organic matter oxidation or increased concentrations of CO_2 and CH_4 which could have lowered the relative concentrations of O_2 .

At the 1972 sampling, CO_2 percentages were higher in the surface 40 cm under the plots receiving 687 MT/ha./yr, and at the 1973 sampling, CO_2 was increased at all sampling depths beneath plots receiving 306 and 687 MT/ha./yr (Figure 40). Higher CO_2 concentrations reflect greater respiration of soil organisms resulting from the addition of organic matter in the manure. More CO_2 was found throughout the surface meter even though organic C was not increased appreciably below 50 cm (Figure 37). This could be explained by diffusion of CO_2 downward.

No CH_2 or N_2O was found in the 1972 gas samples. Analysis of samples taken in 1973 beneath the plot receiving 687 MT/ha./yr of manure did show significant concentrations of CH_4 at all depths except the one closest to the soil surface (Figure 41). No CH_4 was found in samples from three plots. Methane does indicate that anaerobic conditions existed beneath the plot receiving the heaviest manure treatment. Nitrous oxide in the 1973 samples was found in the lower portions of the surface meter under plots receiving the two heaviest manure treatments, but not under the control plot nor the lightest manured plot (Figure 41). Since N_2O is an end product of denitrification, its presence indicates that those reactions did occur.

The soil atmosphere sampling technique was adequate for monitoring the appearance or disappearance of the gases measured. The large, variable

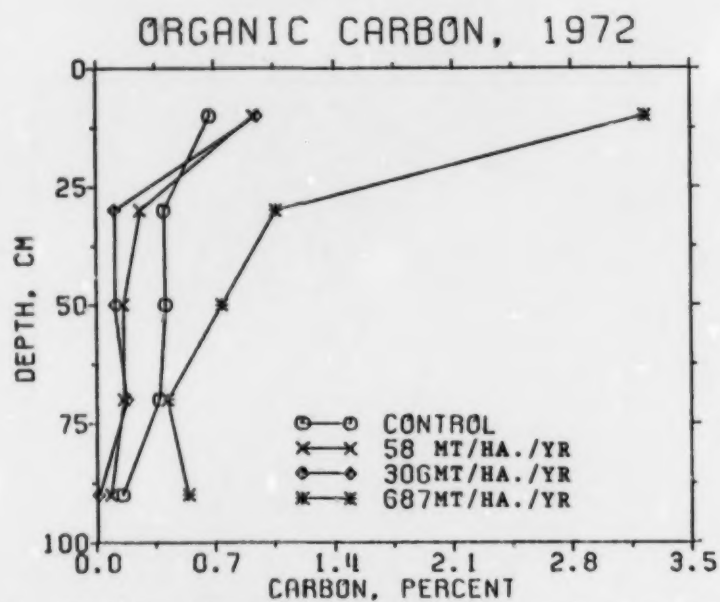
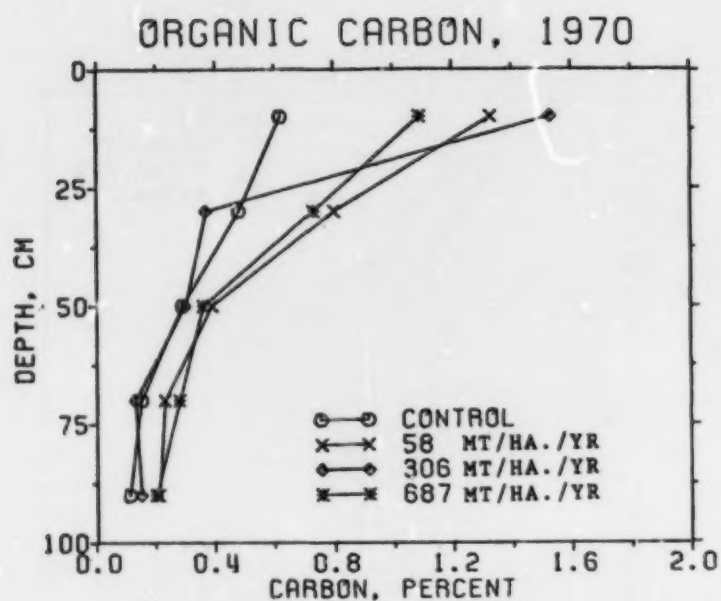


Figure 37. Organic C (dry weight basis) in soil cores as affected by depth and yearly beef feedlot manure applications.

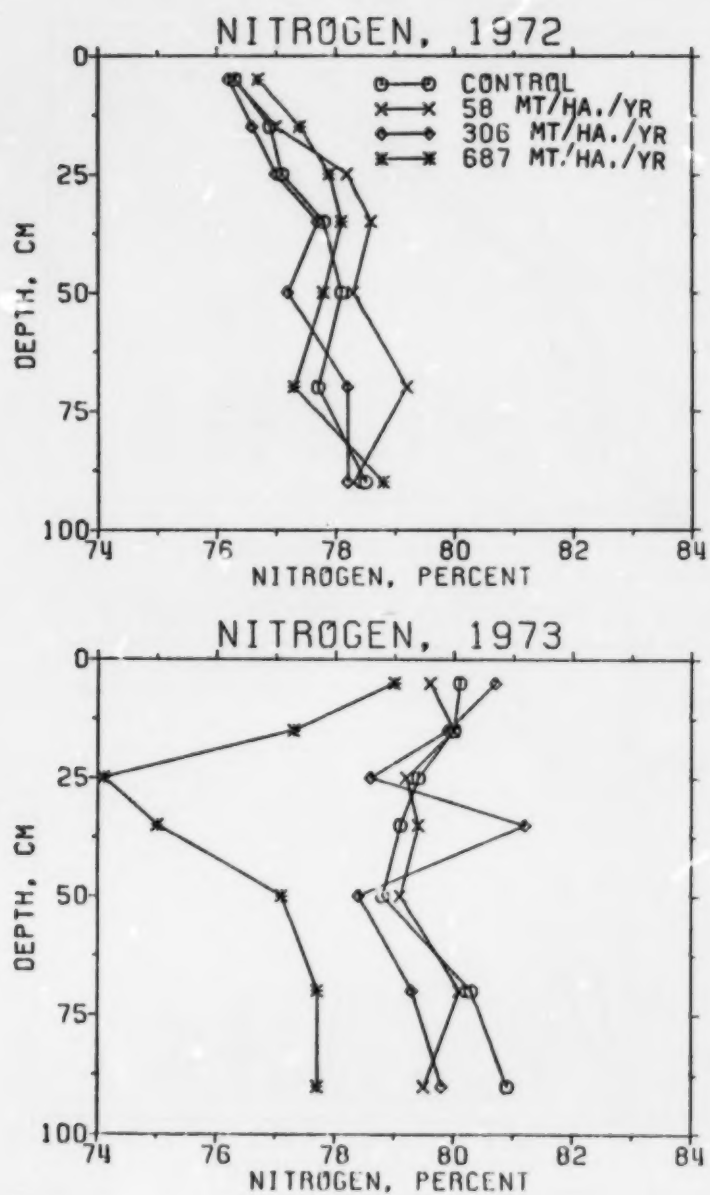


Figure 38. Nitrogen gas in soil atmosphere as affected by depth and yearly beef feedlot manure applications.

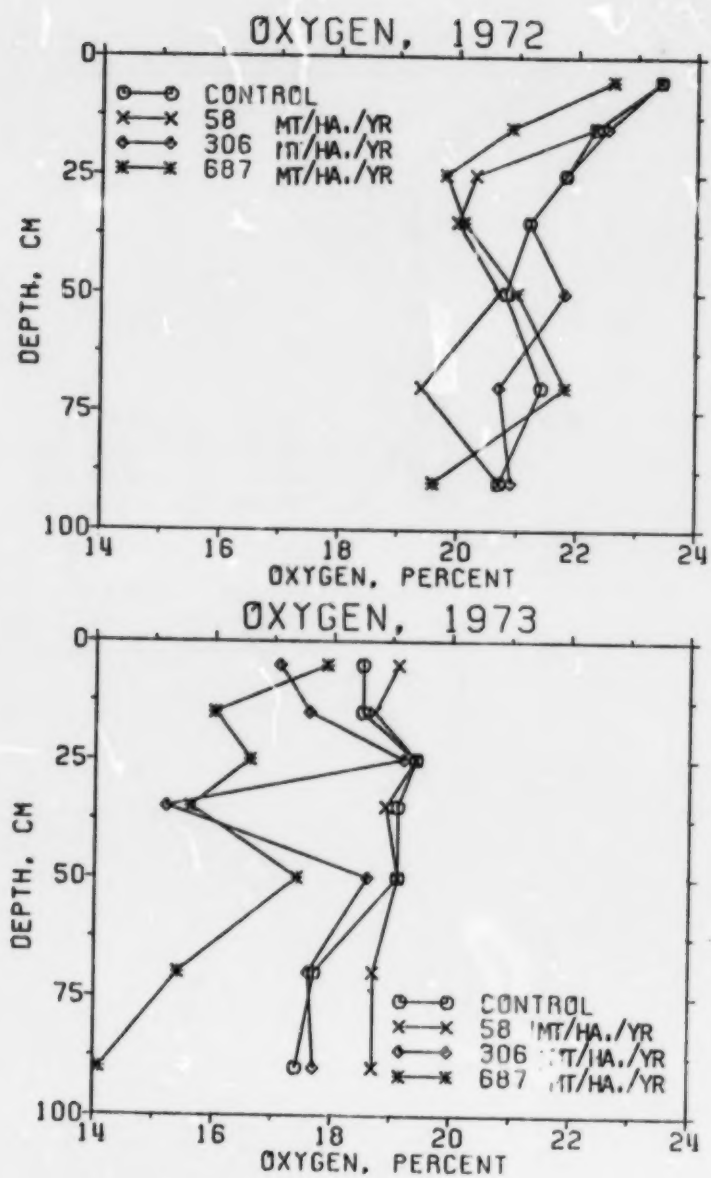


Figure 39. Oxygen gas in soil atmosphere as affected by depth and yearly beef feedlot manure applications.

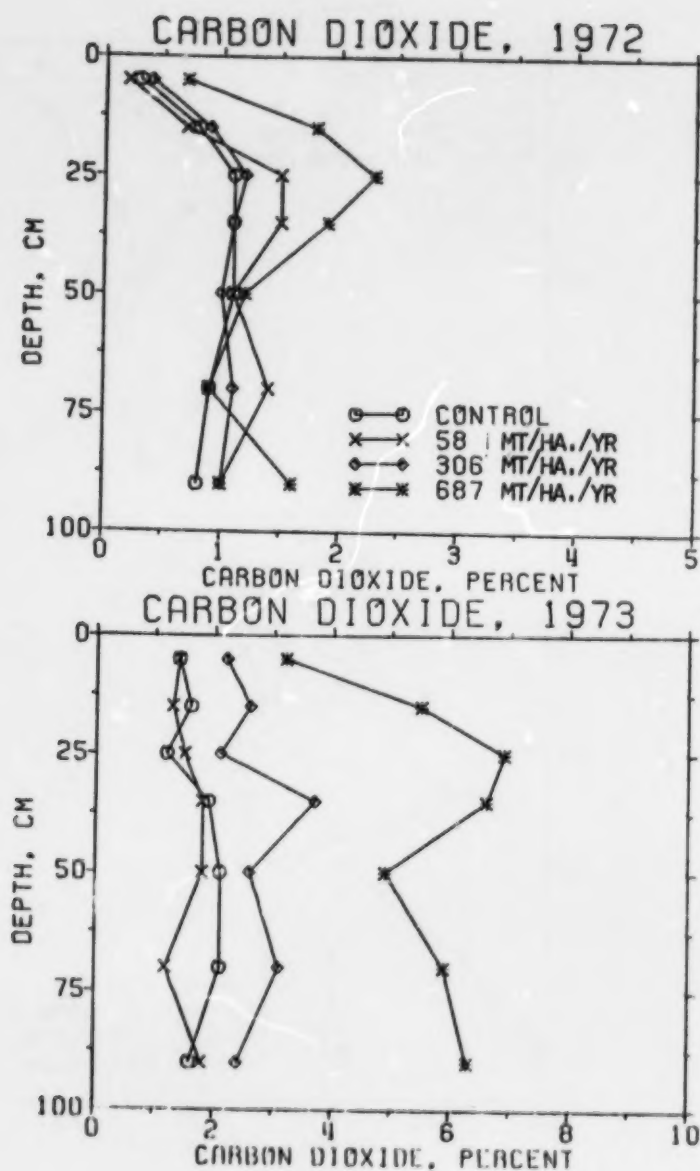


Figure 40. Carbon dioxide in soil atmosphere as affected by depth and yearly beef feedlot manure applications.

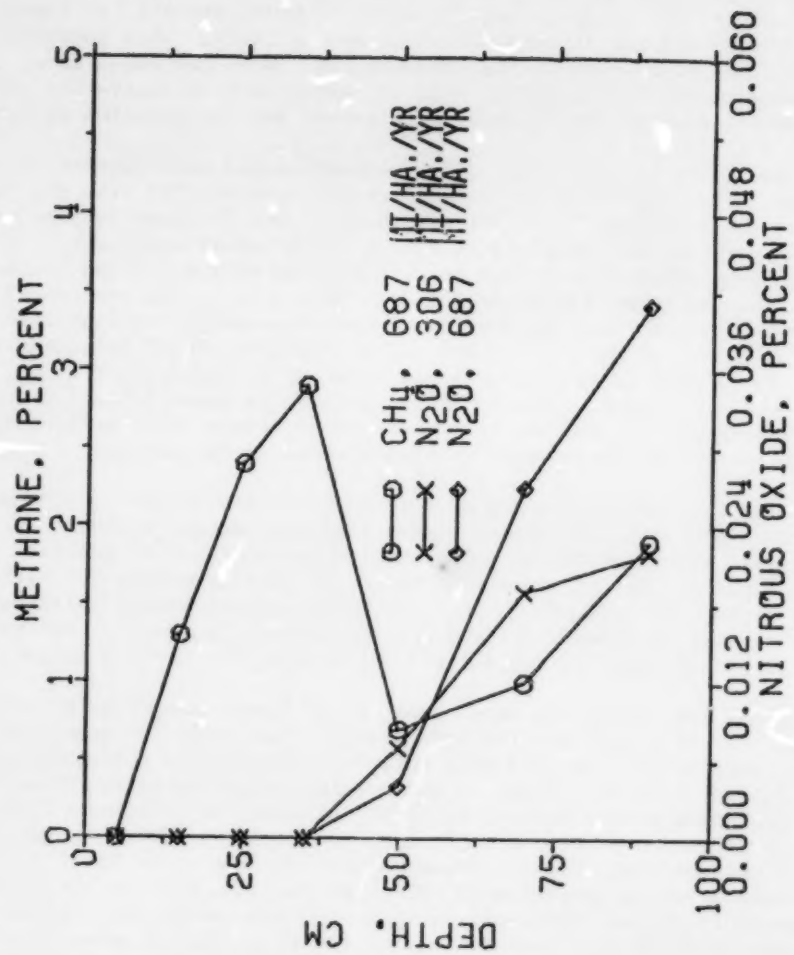


Figure 41. Nitrous oxide and methane in soil atmosphere as affected by depth and yearly beef feed-lot manure applications.

volume of the access tube makes quantification difficult, but profile distributions of relative concentrations were successfully measured.

1972 and 1973 Soil Solution Analyses

Analyses of the 1972 and 1973 soil solution samples were averaged over all sampling dates and are presented in Figures 42-44. The results of the 1972 and 1973 analyses are expressed as parts per million (ppm) in air dry soil and ppm in soil solution, respectively. When comparing the relative magnitudes of the 1972 and 1973 NO_3^- -N and NO_2^- -N data, the 1972 data should be multiplied by 3 to correct the concentration effect that would occur if the dry soil were wetted and the solution analyzed.

Relative to the control plot, NO_3^- -N concentrations were greater throughout the entire surface meter in soil cores taken in 1972 from the three manured plots (Figure 42). The magnitude of NO_3^- -N concentrations were much greater in the two plots receiving the heaviest treatment, indicating large amounts of N were being nitrified into NO_3^- -N and leached downward. Increased NO_2^- -N was found in 1972 only in the surface 25 cm of plots receiving the two heaviest manure treatments. An intermediate product of both nitrification and denitrification, NO_2^- -N indicates at least one of the above reactions was occurring in the surface 25 cm. NH_4^+ -N was also found in higher concentrations in cores taken from the two plots receiving the highest manure rates (Figure 42), reflecting ammonification of nitrogenous compounds added in the manure.

Increased NO_3^- -N concentration were found generally at 50- to 100-cm depths in soil-solution samples taken from the manured plots in 1973. NO_2^- -N was only found in the soil solution beneath the two heaviest manured plots, the concentrations under the plot receiving 687 MT/ha./yr being highest from 50 to 100 cm. The NH_4^+ -N concentrations in the soil solution samples showed no trend due to treatment or depth. The values were generally high beneath all plots including the control (Figure 43).

High NO_3^- -N concentrations were found in the summer samplings of both years. The 1972 soil samples were collected at least one week after irrigations, while the 1973 soil solution samples were taken when the soil was wet from an irrigation and a rain. Later sampling dates in 1972 (relative to wet soil conditions), allowing re-aeration of the soil and nitrification reactions to resume, indicated why NO_3^- -N concentrations were found uniformly higher throughout the surface meter in 1972. The 1973 soil solution samples were collected when the soil was still wet and probably oxygen deficient, conditions conducive to denitrification. Entrance of NO_3^- -N into denitrification reactions caused generally lower concentrations of NO_3^- -N in the surface 50 cm than between 50 and 100 cm in 1973.

Iron in the soil solution samples was higher under the three manured plots than under the control plots. The magnitude of Fe concentrations were greater with the heavier applications (Figure 44). Manganese

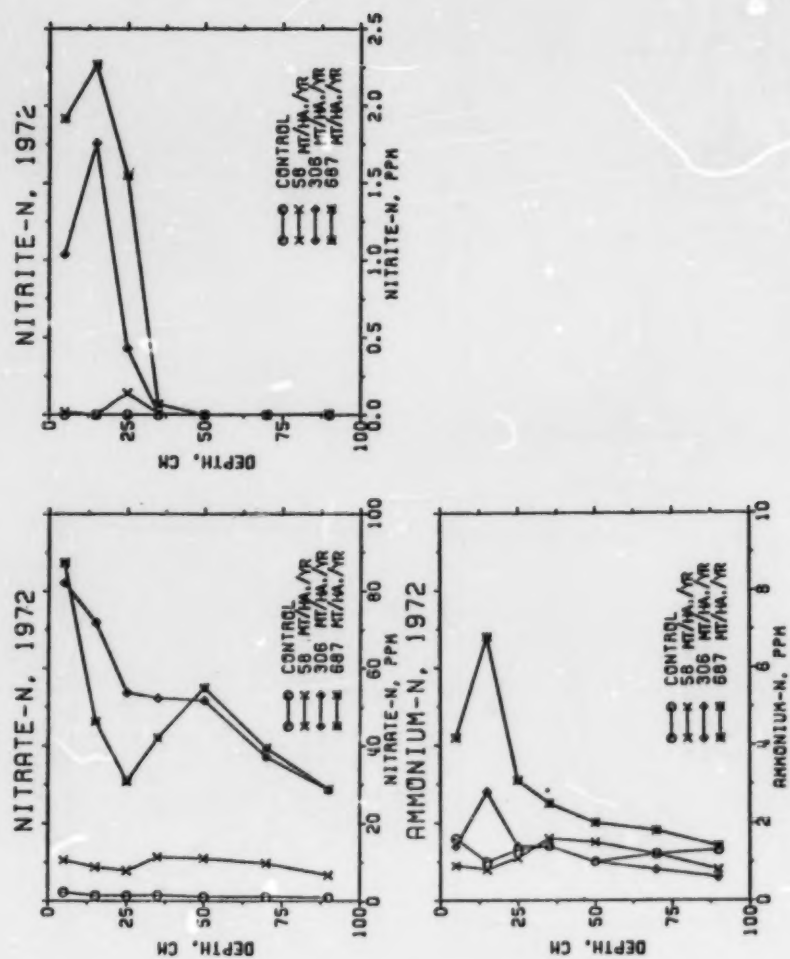


Figure 42. Nitrate-N, nitrite-N, and ammonium-N (dry weight basis) in soil cores as affected by depth and yearly beef feedlot manure applications.

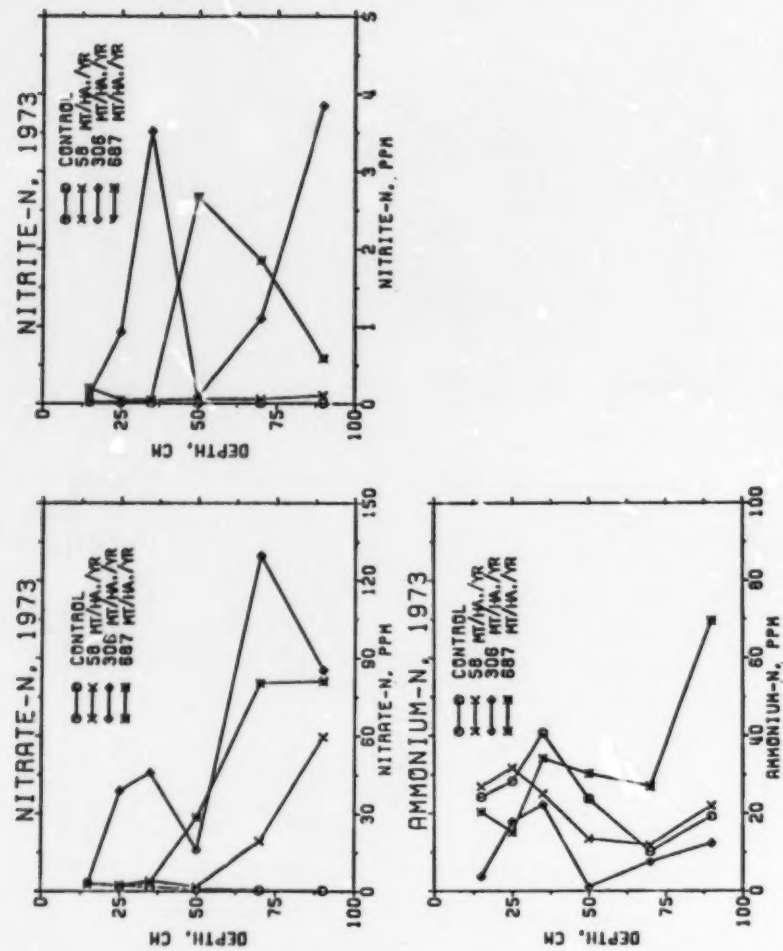


Figure 43. Nitrate-N, nitrite-N, and ammonium-N in soil solution as affected by depth and yearly applications of beef feedlot manure.

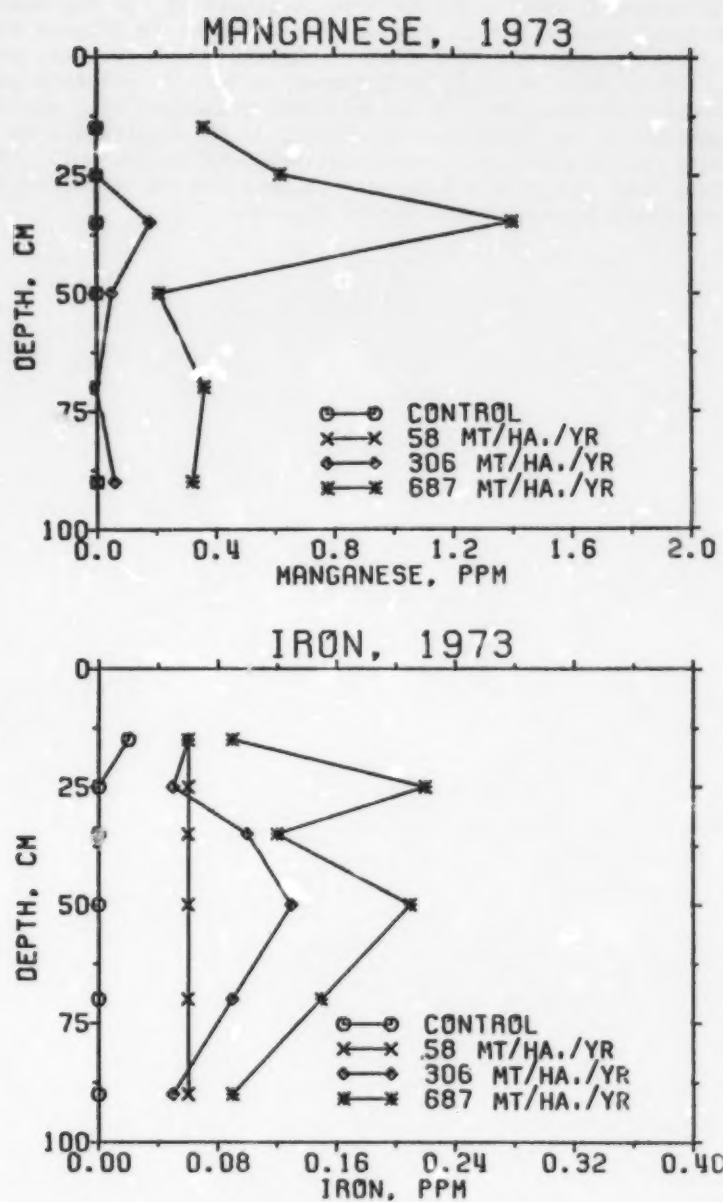


Figure 44. Iron and manganese in soil solution as affected by depth and yearly applications of beef feedlot manure.

concentrations in soil solution were increased by the two heaviest manure treatments to levels higher than those of Fe (Figure 44). The 687 Mt/ha./yr treatment increased Mn throughout the surface meter. Meek et al.⁷¹ found that Mn and, to a lesser extent, Fe solution concentrations were increased when an organic matter-amended soil was flooded. They attributed the increased solubility of these elements to chemical reduction in the anaerobic conditions measured in the soil. Fe and Mn data from this study were indirect evidence for the presence of anaerobic conditions necessary for denitrification.

SECTION XII

RUNOFF FROM LAND APPLICATION OF FEEDLOT WASTES

GENERAL

Success in disposing of feedlot wastes onto cropland depends upon the quality of the surface runoff waters. Characteristics of runoff from irrigations and rainfall were measured on the plots used for disposal of feedlot runoff and feedlot manure.

METHODS AND PROCEDURES

The waste disposal plots have been described in Sections VIII and IX of this report.

During the corn growing season of 1970 and 1971, runoff from the three center furrows of each plot was directed through an orifice in a plate of sheet metal. A sample bottle was connected by a 0.63-cm diameter plastic tube to a 0.31-cm diameter orifice drilled in the sheet metal plate. A second plastic tube vented the sample bottle to the atmosphere at the top of the orifice plate. As runoff occurred, the sample bottle filled from the first runoff. When no further flow could enter, the sample was retained for later analysis in the laboratory.

During the 1973 irrigation season, equipment was installed to measure and sample rainfall runoff from three plots receiving annual applications of manure. Runoff from the center three furrows of each plot was directed through a 2.54-cm trapezoidal flume. Flow was measured by a water level recorder activated by a float. The runoff was sampled every 5 minutes during the runoff event by an automatic vacuum sampler. Grab samples of runoff from irrigations with well water were taken from these three plots and two additional replications of the three treatments. Table 20 gives annual manure treatments to the disposal plots.

Table 20. ANNUAL MANURE APPLICATIONS TO DISPOSAL PLOTS^a
(MT/ha.)

Plot	Year			
	1969	1970	1971	1972
M-1	0	0	0	0
M-4	137	65	152	72
M-9	470	435	692	457

^a Dry Weights.

Samples were collected and refrigerated after each runoff event. They were packed in ice during transport to Manhattan and refrigerated until analyzed.

Chemical oxygen demand and five-day biochemical oxygen demand (BOD₅) were determined according to methods listed in Standard Methods.⁶⁵ Total N determinations were made using the micro-kjeldahl method described by Carter.⁷⁷ Ammonia-nitrogen was determined by the procedure described in Standard Methods⁶⁵ using the direct nesslerization method, and NO₃⁻-N determinations were made with a standard Hach DR-EL direct reading engineers' laboratory kit. Total P determinations were run as described in Standard Methods⁶⁵ using method C and exercising the auto-clave option. The Millipore vacuum filter technique was used for total suspended solids (SS) determinations. Turbidity determinations, expressed in Jackson Turbidity Units (JTU), were made with a Hach Laboratory Turbidimeter Model 1860, and EC was determined using a Lab-Line Lectro Mho Meter Model MC-1, Mark IV.

RESULTS AND DISCUSSION

Quality of Initial Runoff

During 1970 and 1971, samples were initial runoff of a runoff event from the waste disposal plots. The quality of irrigation runoff from the manured plots was relatively good with COD concentrations of 10 to 50 mg/l, total N ranging from 5 to 25 mg/l, and P approximately 1 mg/l. Runoff from rainfall, however, carried a higher pollutant load. COD concentrations ranged from 100 to 400 mg/l with a trend for higher concentrations from the heaviest manure treatments, total N ranged from 14 to 29 mg/l, and P ranged from 3 to 5 mg/l.

Irrigation runoff from disposal plots receiving annual applications of feedlot runoff had COD concentrations of 40 to 90 mg/l and total N ranging from 22 to 27 mg/l. Runoff from rainfall had CODs ranging from 100 to 600 mg/l and total N ranging from 15 to 25 mg/l.

Table 21. CHARACTERISTICS OF RAINFALL RUNOFF

Plot	COD mg/l		BOD ₅ mg/l		SS mg/l		Turbidity JTU		Conductivity mmhos/cm	
	range	mean	range	mean	range	mean	range	mean	range	mean
July 20, 1973										
M-9	118-716	473	4.0-13.4	8.8	144-1,156	477	29-340	164	0.53-4.70	2.96
September 2, 1973										
M-1	101-601	232	9.5-22.5	16.1	172- 664	420	61-155	98	0.20	0.20
M-4	83-201	120	4.7- 6.4	5.4	328- 668	479	55-190	118	0.17-0.19	0.18
September 12, 1973										
M-9	117-459	180	7.6- 8.1	7.8	168- 394	276	32-300	122	0.53-0.68	0.57
September 16, 1973										
M-1	66-122	82	4-6- 8.6	6.4	171- 564	242	120-185	134	0.10-0.13	0.12
M-9	161-241	174	5.4- 9.2	7.0	192- 852	3.2	96-235	122	0.70-0.94	0.88

Table 22. CHARACTERISTICS OF RAINFALL RUNOFF

Plot	Total N mg/l		NO ₃ -N mg/l		NH ₄ -N mg/l		Total P mg/l	
	range	mean	range	mean	range	mean	range	mean
July 30, 1973								
M-9	5.8-35.5	22.7	3.7-97.0	61.6	1.1-4.0	2.7	6.26-19.18	13.97
September 2, 1973								
M-1	1.9- 6.0	4.6	0.0- 0.8	0.3	1.0-1.8	1.0	0.85- 3.59	1.78
M-4	2.9- 5.0	3.9	0.3- 0.8	0.3	0.4-1.3	1.2	0.85- 2.22	1.59
September 12, 1973								
M-9	5.0-33.8	7.5	3.5-37.0	6.4	1.0-2.8	1.3	3.43- 5.42	4.50
September 16, 1974								
M-1	0.9- 2.9	2.5	0.8- 1.8	1.0	0.0-0.7	0.2	0.98- 1.15	1.08
M-9	7.6- 8.2	7.8	9.3-10.3	9.9	0.9-1.6	1.0	3.45- 3.82	3.68

The higher concentration of COD in the rainfall runoff can be attributed to erosion due to impact of the falling raindrops onto the soil. The entire plot area contributed during rainfall while during irrigations only the weathered area in the furrows contributed to runoff.

Quality of Runoff from Manured Plots, 1973

The runoff samplers were installed on June 5, 1973, and operated through September 17, 1973. During this time, samples were collected from four irrigations with well water and four of the five runoff-producing rainfall events. Due to mechanical difficulties with the automatic samplers, samples were not collected from all three plots during each rainfall-runoff event.

Tables 21 and 22 give dates and characteristics of runoff from rainfall. The rainfall event on July 30 was three weeks after the corn was furrowed for irrigation and 15 days after the first irrigation. The storm was of high intensity and came when the corn plants were about one-third of their mature size. Runoff in September occurred under ideal conditions for minimum pollution concentrations as the crop was nearing maturity and the soil had not been cultivated for several months.

As samples were not collected from each treatment during each runoff event, it was impossible to directly evaluate the effects of manure treatment on runoff quality. COD was chosen as the basis for comparing the various pollutional parameters because it was highly correlated with other pollutional parameters for feedlot runoff (Section V of this report). Table 23 gives selected mean COD:pollutional parameter ratios for individual runoff events.

Table 23. MEAN COD:POLLUTION PARAMETER RATIO

Plot	COD:BOD ₅	COD:Total N	COD:Total P	COD:SS
I M-9	54:1	6:1	34:1	1:1
II M-1	14:1	47:1	130:1	1:2
II M-4	22:1	29:1	75:1	1:4
III M-9	23:1	13:1	40:1	1:2
IV M-1	13:1	23:1	76:1	1:3
IV M-9	25:1	10:1	47:1	1:2

BOD₅ was consistently below 10 mg/l (Table 21) indicating that the BOD₅ load applied by the waste was assimilated by the microorganisms in the soil. Therefore, the BOD₅ data indicate a background level caused by material always present in the soil and were not influenced by waste

application the previous October. The COD was not completely assimilated, so higher waste applications result in higher COD losses. This is shown by the ratios (Table 23) where less COD was given off per unit of BOD₅ from the lower pollution potential plots, M-1 and M-4.

Table 22 shows that for the check plot, M-1, and the lower waste application, M-4, most of the N and P was assimilated by the soil leaving only a small residual to react with the elements and leave in runoff. Of the heavy waste application, M-9, only a portion of the total N and P could be assimilated by the soil leaving a larger residual to react with the elements and remain in runoff. Since soil has a limited capacity for COD reduction, as waste application increased, so did residual which can be acted upon and lost. The ratios (Table 23) show this by the fact that more COD per unit of total N and P was given off on the lower pollution-potential plots.

COD:SS ratios in Table 23 show no trend. There is sufficient cause to state that a significant portion of the COD was soluble and not related to suspended solids. It appears that the concentration of suspended solids in the runoff is based upon storm intensity and soil conditions.

Tables 24 and 25 give dates and characteristics of irrigation runoff. The irrigation on June 15 was about one week after the plots were furrowed and light rainfall fell during the later stages of the irrigation. These factors account for the higher pollutant concentrations for this irrigation.

As for the rainfall runoff events, the irrigation runoff events and their associated pollutional parameters were compared on a COD basis. No trends could be defined when the mean ratios were examined.

Table 24. CHARACTERISTICS OF IRRIGATION RUNOFF

Plot	COD mg/l		BOD ₅ mg/l		SS mg/l		Turbidity JTU		Conductivity mahos/cm	
	range	mean	mean	range	mean	range	mean	range	mean	
First Irrigation - June 15, 1973										
M-1	23- 94	50	4.80	50-260	132	0.58-0.62		0.61		
M-4	18- 34	25	5.36	39- 78	55	0.61-0.64		0.63		
M-9	68-160	110	5.00	11-120	52	0.84-1.10		0.95		
Second Irrigation - July 2, 1973										
M-1	10- 39	26	4.50	6-100	55	0.54-0.61		0.57		
M-4	8- 16	12	2.14	4- 24	14	0.56-0.60		0.58		
M-9	27- 64	46	5.06	3- 22	11	0.63-0.82		0.69		
Third Irrigation - August 6, 1973										
M-1	3- 6	5	6.26	2- 12	7	0.50-0.63		0.57		
M-4	2- 15	8	3.24	1- 4	2	0.49-0.61		0.55		
M-9	24- 72	41	4.95	2-115	51	0.60-0.73		0.64		
Fourth Irrigation - August 20, 1973										
M-1	6- 8	7	3.45	7- 8	8	0.55-0.59		0.57		
M-4	8- 18	12	2.50	15- 36	25	0.51-0.60		0.56		
M-9	29-139	78	3.10	7-135	52	0.64-0.88		0.74		

Table 25. CHARACTERISTICS OF IRRIGATION RUNOFF

Plot	Total N mg/l		NO ₃ -N mg/l		NH ₄ -N mg/l		Total P mg/l	
	range	mean	range	mean	range	mean	range	mean
First irrigation - June 15, 1973								
M-1	0.4-3.3	1.5	1.0-3.0	1.7	0.0	0.0	0.13-0.44	0.29
M-4	0.4-1.2	0.9	5.0-7.0	6.0	0.0	0.0	0.24-0.79	0.47
M-9	1.7-7.2	4.6	2.0-4.0	2.7	0.3	0.3	3.46-5.22	4.53
Second irrigation - July 2, 1973								
M-1	0.4-1.6	0.9	1.8-2.8	2.2	0.1	0.1	0.0-0.34	0.15
M-4	0.5-0.8	0.6	2.0-2.2	2.1	trace	trace	0.11-0.36	0.27
M-9	1.1-2.2	1.8	2.8-3.8	3.2	0.3	0.3	0.85-1.05	0.92
Third irrigation - August 6, 1973								
M-1	0.5	0.5	3.5-3.8	3.7	1.3	1.3	0.02-0.35	0.15
M-4	0.5	0.5	3.9-4.4	4.1	0.0	0.0	0.0-0.16	0.09
M-9	1.3	1.3	3.5-4.2	3.8	0.5	0.5	0.79-1.90	1.51
Fourth irrigation - August 20, 1973								
M-1	0.4	0.4	4.0-4.6	4.3	0.0	0.0	0.04-0.11	0.08
M-4	0.1	0.1	3.9-4.5	4.3	0.0	0.0	0.06-0.24	0.16
M-9	1.9	1.9	3.4-5.1	4.4	0.6	0.6	2.09-5.84	3.37

SECTION XIII

MOVEMENT OF WATER INTO SOIL RECEIVING FEEDLOT MANURE

GENERAL

Incorporation of feedlot manure into soil will alter the soil's chemical and physical composition. Changes in soil composition will most likely change water intake characteristics. The effect of manure loading rate on the basic intake rate of irrigation water into the soil was evaluated.

METHODS AND PROCEDURES

The study was conducted on the manure disposal area described in Section IX of this report. Corn was irrigated with well water in furrows on 0.76-m spacing in 1970, 1971, and 1972 and 1.52-m spacing in 1973. Basic intake rates were determined from inflow and outflow measurements during each irrigation.

During each irrigation, water was delivered to the furrows for 30 to 48 hours. A basic intake rate was assumed after the runoff hydrograph leveled off, 6 to 12 hours after runoff began. Inflow and runoff were measured for three furrows in 1970, 1971, and 1972 and two furrows in 1973 of each plot a minimum of three times during the basic intake period. Intake rates were taken as the difference between inflow and outflow and were calculated assuming the entire soil surface was covered with water. The basic intake rate for each plot during each irrigation was taken as the average of the calculated basic intake rates. Stritzke⁷⁸ gives further details of inflow and outflow measurements and intake rate calculations.

RESULTS AND DISCUSSION

Table 26 gives basic intake rates in centimeters per hour (cm/hr), dates of irrigations, and dry manure application rates. As furrows were on 1.52-meter spacing in 1973 and 0.76-meter spacing the other years, basic intake rates for 1973 cannot be compared directly with those for the other years.

Table 26. MANURE APPLICATION RATE AND BASIC INTAKE RATE

Plot	Manure MT/ha.	Basic Intake Rate cm/hr				Manure MT/ha.	Basic Intake Rate cm/hr			
		6/25/70	7/09/70	7/23/70	8/06/70		4/06/71	7/13/71	7/27/71	8/10/71
11	137	0.274	0.157	0.224	0.339	65	0.325	0.257	0.206	0.150
12	159	0.175	0.109	0.097	0.170	184	0.282	0.140	0.168	0.135
13	455	---	0.061	0.048	0.046	0	0.130	0.246	0.211	0.208
14	0	---	0.193	0.221	0.282	0	0.175	0.170	0.572	0.404
15	470	0.401	0.114	0.175	0.206	435	0.196	0.086	0.086	0.160
16	63	---	0.208	0.310	0.394	31	0.127	0.191	0.097	0.140
17	269	---	---	0.097	0.140	0	0.160	0.140	0.056	0.058
18	327	---	0.147	0.178	0.213	296	0.081	0.107	0.157	0.058
19	215	---	---	---	---	0	0.269	0.051	0.028	0.030
20	20	---	0.145	0.124	0.178	34	0.056	0.142	0.119	0.135
21	414	0.127	0.122	0.122	0.124	558	0.213	0.363	0.069	0.142
22	141	0.302	0.384	0.366	0.373	112	0.335	0.472	0.312	0.345
23	72	0.086	0.109	0.074	0.030	128	---	---	---	---
24	0	0.218	0.165	0.168	0.191	0	0.023	0.211	0.063	0.015
25	54	0.066	0.089	0.071	0.079	29	0.135	0.241	0.061	0.030
26	20	0.211	0.107	0.147	0.145	18	0.033	0.175	0.005	0.003
27	123	0.163	0.130	0.163	0.178	0	0.003	0.376	0.135	0.076
28	589	---	---	---	---	0	0.018	0.157	0.081	0.043
29	372	0.066	0.043	0.018	---	0	0.262	0.279	0.114	0.119
30	302	0.183	0.147	0.175	0.165	444	0.269	0.287	0.201	0.175
31	233	0.135	0.170	0.071	0.168	0	0.282	0.432	0.335	0.208
32	609	0.084	0.076	0.046	0.023	569	0.015	0.036	0.010	0.008
33	204	---	---	---	---	0	0.312	0.302	0.236	0.208
34	506	---	---	0.056	0.102	0	0.023	0.185	0.127	0.089
35	0	0.104	0.122	0.127	0.119	0	0.109	0.152	0.086	0.155
36	76	0.193	0.183	0.140	0.145	128	0.226	0.180	0.066	0.036
37	226	0.109	0.064	0.058	0.114	343	0.005	0.384	0.137	0.109
38	175	0.061	0.071	0.079	0.097	226	---	---	---	---
39	47	0.244	0.259	0.244	0.442	16	0.089	0.269	0.155	0.056
30	38	0.170	0.061	0.099	0.124	40	0.036	0.272	0.462	0.066

Table 26 (Continued). MANURE APPLICATION RATE AND BASIC INTAKE RATE

Plot	Manure MT/ha.	Basic Intake Rate		Manure	Basic Intake Rate	
		7/20/72	8/02/72		7/02/73	8/06/73
		cm/hr			cm/hr	
11	152	0.302	0.371	72	---	---
12	188	0.284	0.282	157	0.091	0.081
13	0	0.409	0.198	0	0.063	0.046
14	0	0.427	0.201	0	---	---
15	692	0.404	0.180	457	0.033	0.003
16	76	0.274	0.130	83	0.132	0.028
17	0	0.297	0.157	0	0.150	0.094
18	439	0.282	0.150	202	0.104	0.063
19	0	0.434	0.290	0	0.145	0.071
20	31	0.845	0.259	29	0.157	0.114
21	423	0.386	0.257	654	---	0.155
22	202	0.315	0.185	159	0.076	0.168
23	110	0.071	---	108	0.119	0.127
24	0	---	---	0	0.013	0.089
25	78	0.442	0.030	0	0.127	0.097
26	34	0.196	0.008	67	0.157	0.074
27	0	0.191	0.030	56	0.155	0.089
28	0	0.236	0.038	0	0.175	0.122
29	0	0.325	0.193	0	0.226	0.081
30	390	0.025	0.038	184	0.114	0.058
31	0	---	---	0	0.069	0.152
32	977	0.145	0.058	0	0.170	0.081
33	0	0.282	0.076	591	0.305	0.142
34	0	0.221	0.132	0	0.028	0.107
35	0	---	0.081	0	0.046	0.064
36	242	0.208	0.130	148	0.168	0.132
37	340	0.183	---	314	0.348	0.112
38	213	0.21	0.025	179	0.041	0.175
39	31	---	0.211	29	0.005	0.152
40	103	---	---	52	0.378	0.117

Basic intake rates for the three replicated blocks were pooled and analyzed by multiple regression methods. The following equations were developed:

$$\begin{aligned} \ln I_{70} = & -1.85 - 6.32 \times 10^{-4} M_{69} + 3.66 \times 10^{-7} M_{69}^2 \\ & - 3.42 \times 10^{-9} M_{69}^3, \quad R^2 = 0.16 \end{aligned} \quad (8)$$

$$\begin{aligned} \ln I_{71} = & -2.50 + 8.58 \times 10^{-3} M_{69} + 7.39 \times 10^{-6} M_{69}^2 \\ & - 3.72 \times 10^{-8} M_{69}^3 - 2.64 \times 10^{-3} M_{70} - 1.50 \times 10^{-5} M_{70}^2 \\ & + 2.77 \times 10^{-8} M_{70}^3, \quad R^2 = 0.25 \end{aligned} \quad (9)$$

$$\begin{aligned} \ln I_{72} = & -2.11 + 2.92 \times 10^{-2} M_{69} - 7.24 \times 10^{-5} M_{69}^2 \\ & - 2.16 \times 10^{-8} M_{69}^3 + 2.68 \times 10^{-2} M_{70} - 1.80 \times 10^{-4} M_{70}^2 \\ & + 2.50 \times 10^{-7} M_{70}^3 + 3.30 \times 10^{-2} M_{71} + 1.06 \times 10^{-4} M_{71}^2 \\ & - 6.27 \times 10^{-8} M_{71}^3, \quad R^2 = 0.30 \end{aligned} \quad (10)$$

$$\begin{aligned} \ln I_{73} = & -2.55 - 4.24 \times 10^{-2} M_{69} + 2.26 \times 10^{-4} M_{69}^2 \\ & - 3.56 \times 10^{-7} M_{69}^3 + 3.07 \times 10^{-3} M_{70} - 3.65 \times 10^{-5} M_{70}^2 \\ & + 6.14 \times 10^{-8} M_{70}^3 + 2.47 \times 10^{-2} M_{71} - 8.14 \times 10^{-5} M_{71}^2 \\ & + 7.85 \times 10^{-8} M_{71}^3 + 5.07 \times 10^{-3} M_{72} - 4.55 \times 10^{-6} M_{72}^2 \\ & + 1.86 \times 10^{-9} M_{72}^3, \quad R^2 = 0.47 \end{aligned} \quad (11)$$

where $\ln I$ = Natural logarithm of basic intake rate for year of subscript, cm/hr
 M = Dry manure application for year of subscript, MT/ha.
 R = Coefficient of multiple correlation

Data from all plots were used to generate the intake rate equation for 1970. Data for the residual plots, those receiving manure the first year only, were omitted from the 1971, 1972, and 1973 analyses. Although the equations explain only 16 to 42 percent of the variation between basic intake rate and manure application rate, the correlation coefficients were statistically significant at the 0.01 level.

Yearly basic intake rates were calculated from Equations 8-11 assuming constant yearly manure applications. For 1970, basic intake rate gradually decreased as manure application increased. Basic intake rate increased with increasing annual manure application up to 262 and 93 metric tons per hectare for 1971 and 1972, respectively, and then decreased. For 1973, basic intake rate decreased slightly as annual manure application increased from 0 to 55 metric tons per hectare, increased for annual manure applications of 55 to 269 metric tons per hectare, and decreased for higher manure applications.

The increase in basic intake rate for the lower to medium annual manure applications was attributed to an increase of organic matter in the soil. Decreases in basic intake rate for high annual manure applications were due to increased levels of sodium and potassium in the soil. Although the basic intake rate prediction curve for 1973 was anticipated to be similar to 1971 and 1972 with a peak at a lower annual manure application rate, rainfall during November through March preceding the 1973 growing season (41.35 cm) leached salts downward in the soil profile, reducing the detrimental effects on basic intake rate.

The basic rates for the residual manure treatments were depressed in 1970. However, basic intake rates were equal to or higher than the control plots in subsequent years.

SECTION XIV

ECONOMICS OF WASTE APPLICATION TO LAND

GENERAL

Feedlot wastes may be applied to land with waste disposal as the main objective or they may be applied as a fertilizer to increase crop yields. The most economical rate for applying feedlot runoff and manure to land at the Pratt Feedlot, Inc. was determined.

METHODS AND PROCEDURES

Corn forage yield prediction equations were developed for annual applications of feedlot runoff and for annual and single year applications of feedlot manure from data collected in the studies described in Sections VIII and IX of this report.

Equations were developed to determine annual net income from crop production on the area required for disposal of wastes at the Pratt Feedlot, Inc. It was assumed that land area for waste disposal was unlimited and that no other fertilizer was used. The most economical waste application rates were determined from the net income equations using yield prediction equations and 1974 prices.

Maximum net income results when the return from the last unit of fertilizer added is equal to its cost. As a larger volume of material must be applied to supply a unit of plant nutrient through feedlot waste than through commercial fertilizer, it was assumed that wastes would be spread onto land near the feedlot to keep hauling costs to a minimum and that wastes would be the only fertilizer used. Equations were developed to determine net income per hectare from corn production using feedlot wastes as fertilizer. The most profitable waste application rates were determined by substituting yield prediction equations and 1974 prices into the net income equations.

RESULTS AND DISCUSSION

Feedlot Runoff Disposal

The following corn forage yield prediction equations were developed from the runoff disposal studies:

$$Y_{70} = 0.498 E + 41.5, \quad R^2 = 0.32 \quad (12)$$

$$Y_{71} = -0.0164 E^2 + 0.85 E + 36.3, \quad R^2 = 0.37 \quad (13)$$

$$Y_{72} = -0.02898 E^2 + 1.278 E + 49.2, \quad R^2 = 0.27 \quad (14)$$

$$Y_{73} = -0.01696 E^2 + 0.98 E + 33.8, \quad R^2 = 0.33 \quad (15)$$

where Y_{70} = Corn forage yield in year of subscript, MT/ha.
 E = Annual runoff application, cm
 R = Coefficient of multiple regression

In 1970, yields continued to increase as feedlot runoff application rates increased up to the heaviest treatment which was 35 cm. The positive effect on yield was attributed to increased availability of plant nutrients throughout the growing season. Maximum predicted yields resulted from annual feedlot runoff applications of 26 cm in 1971, 22 cm in 1972, and 29 cm in 1973. As yield depression at the higher feedlot runoff application rates was due to salt buildup in the soil, the lower yield depression in 1973 was due to leaching of salts downward by the above normal rainfall.

Annual net income from farming operations to dispose of effluent from runoff catchment reservoirs where no additional fertilizer is added can be expressed as:

$$I_n = P_f Y A - C_p A - C_e E A \quad (16)$$

where I_n = Annual net income, \$
 P_f = Selling price of corn forage, \$/MT
 Y = Corn forage yield, MT/ha.
 A = Area farmed, ha.
 C_p = Cost of corn forage production, \$/ha.
 C_e = Cost of applying runoff, \$/ha.-cm
 E = Annual runoff application rate, cm

The cost of corn production can be expressed as:

$$C_p = C_f + C_1 + C_4 \quad (17)$$

where C_f = Cost of field operations, \$/ha.
 C_l = Cost of land, \$/ha.
 C_i = Cost of irrigation, \$/ha.

The cost of irrigation is:

$$C_i = C_w W \quad (18)$$

where C_w = Cost of applying water, \$/cm
 W = Depth of water applied, cm

Assuming the runoff applied reduces the amount of irrigation water needed, the cost of irrigation becomes:

$$C_i = C_w (W - E) \quad (19)$$

The area farmed to dispose of the runoff is:

$$A = \frac{T_e}{E} \quad (20)$$

where T_e = Annual runoff from feedlot, ha.-cm

Upon substituting Equations 17, 18, 19, and 20 into Equation 16, the annual net income becomes:

$$I_n = \frac{P_f Y T_e}{E} - \frac{T_e}{E} (C_f + C_l + C_w W - C_w E) - C_e T_e \quad (21)$$

The selling price of corn forage was \$15 per MT. Equations 12 to 15 predict corn forage yield. The cost of field operations which includes tillage, planting, and weed control was \$125 per ha. The cost of land which includes interest on the investment and property taxes was \$200 per hectare. Although the cost of irrigation, including depreciation on the system, interest on the investment, and operating costs, is quite variable, it was assumed to be \$4 per hectare-centimeter (ha.-cm) for the Pratt area which has an average annual irrigation requirement of 40 cm. As feedlot runoff can be applied through the irrigation system, the cost of applying runoff was assumed to be the same as for irrigation water. Total runoff available for annual disposal was considered to be constant for a given feedlot.

The annual runoff application rate which gave maximum net income was calculated for each year from Equation 21, using the above values for the parameters. For each of the four years, maximum net income resulted from the application of the first unit of runoff. These results are

consistent with the results from most fertility studies which show that crop yields increase at a decreasing rate as fertilizer application rates increase.

Estimated cost of corn production was \$485 per ha. Cost of corn production would have had to exceed \$622, \$544, \$738, and \$507 per ha. for 1970 to 1973, respectively, before it would have been economical to apply feedlot runoff with disposal as the main objective rather than using it as a fertilizer.

When feedlot runoff is used as a fertilizer, net income per hectare can be expressed as:

$$i_n = P_f Y - C_f - C_l - C_w W + C_w E - C_e E \quad (22)$$

where i_n = Net income, \$/ha.

Maximum net income resulted from the feedlot runoff application rate which gave highest yields. If the cost of applying feedlot runoff is less than for applying irrigation water, maximum net income would result from higher feedlot runoff application rates. On the other hand, if the cost of applying feedlot runoff exceeds the cost of applying well water or if supplemental irrigation is not practiced, maximum net income would result from lower feedlot runoff application rates.

Manure Disposal--Annual Applications

The following corn forage yield prediction equations were developed from the study area receiving annual applications of manure:

$$Y_{70} = -0.000127 M^2 + 0.0583 M + 45.4, \quad R^2 = 0.25 \quad (23)$$

$$Y_{71} = -0.0001784 M^2 + 0.0536 M + 37.5, \quad R^2 = 0.49 \quad (24)$$

$$Y_{72} = -0.0459 M + 60.2, \quad R^2 = 0.48 \quad (25)$$

$$Y_{73} = -0.0001488 M^2 + 0.0556 M + 42.4, \quad R^2 = 0.51 \quad (26)$$

where M = Annual manure application (dry weight), MT/ha.

Maximum predicted yields resulted from annual manure applications of 230, 150, 0, and 187 MT/ha. for 1970 through 1973, respectively.

Annual net income from farming operations to dispose of feedlot manure where no additional fertilizer is added can be expressed as:

$$I_n = P_f YA - A(C_f + C_l + C_i) - C_m MA \quad (27)$$

where C_m = Cost of applying manure, \$/MT

The area farmed to dispose of the manure is:

$$A = \frac{T_m}{M} \quad (28)$$

where T_m = Annual manure from feedlot (dry weight), MT

Upon substituting Equation 28 into Equation 27, the annual net income becomes:

$$I_n = \frac{P_f Y T_m}{M} - \frac{T_m}{M} (C_f + C_l + C_i) - C_m T_m \quad (29)$$

Equations 23 to 26 predict corn forage yields. Cost of applying irrigation water was \$160 per hectare. Cost of applying manure to land which includes cleaning of pens, hauling to the stockpile, loading from the stockpile, hauling to fields, and spreading onto land was \$4.95 per metric ton. Manure application costs were based upon measurements which show the average moisture content of manure taken from the stockpile was 33% on a dry weight basis and current manure handling costs of \$3.30 per MT of material. Other prices and costs were the same as for the feedlot runoff analyses.

The annual manure application rate which gave maximum net income was calculated for each year by Equation 29. As for feedlot runoff, maximum net income resulted from the application of the first unit of manure. Cost of corn production would have had to exceed \$681, \$562, \$903 and \$636 per ha. for 1970 to 1973, respectively, before it would have been economical to apply manure with disposal as the main objective rather than using it as a fertilizer.

When manure is used as a fertilizer, net income per hectare becomes:

$$I_n = P_f Y - C_f - C_l - C_i - C_m M \quad (30)$$

For each of the four years, cost of applying manure exceeded income from the manure. Cost of applying manure would have had to have been \$0.87, \$0.80, \$0.69 and \$0.83 per MT for 1970 through 1973, respectively, before it would have been profitable to apply the first unit of manure.

There are two possible reasons why returns from annual manure applications were less than costs of applying manure. First, the soil had a high initial fertility level as evidenced by high yields from the check plots throughout the study. Secondly, available nitrogen may have been limiting under low annual manure applications. Herron and Erhart²⁴ found that 50% of the nitrogen in feedlot manure was removed by sorghum

the first year after it was applied. Manure at low annual application rates may not have provided sufficient available nitrogen for optimum corn growth during the study.

Manure Disposal--First Year Only

The following corn forage yield prediction equations were developed from the study area receiving manure the first year only:

$$Y_{70} = -0.000127 M^2 + 0.0583 M + 45.4, \quad R^2 = 0.25 \quad (31)$$

$$Y_{71} = -0.0000991 M^2 + 0.0638 M + 34.1, \quad R^2 = 0.21 \quad (32)$$

$$Y_{72} = -0.0000561 M^2 + 0.0364 M + 54.8, \quad R^2 = 0.16 \quad (33)$$

$$Y_{73} = -0.000106 M^2 + 0.0947 M + 32.0, \quad R^2 = 0.69 \quad (34)$$

Maximum predicted yields resulted from first year only applications of 230, 322, 324 and 447 MT/ha. for 1970 through 1973, respectively.

As manure was added the first year and no other fertilizer was added in subsequent years, increases in corn forage yield from manure during the study were due to the first year's application. Net income from manure was determined from Equation 30 using the same prices and costs as for annual manure applications. The corn forage prediction equations substituted into Equation 30 were Equation 31, Equations 31 plus 32, Equations 31 plus 32 plus 33, and Equations 31 plus 32 plus 33 plus 34 for 1970 through 1973, respectively.

At the end of the 1973 season, accumulated returns from manure were insufficient to pay application costs of \$4.95 per MT. However, returns were sufficient to pay for the first unit of manure at an application cost of \$3.80 per MT. The 1974 yield prediction equation indicates residual effects from the single year's application of manure will continue to increase corn forage yields in the future. It appears that increased yields from the manure in subsequent years will make for profitable manure use as a fertilizer.

SECTION XV

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SECTION XVII

GLOSSARY OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

BOD	-- biochemical oxygen demand
BOD ₅	-- 5 day biochemical oxygen demand
cm	-- centimeter
cm/hr	-- centimeter per hour
cm/yr	-- centimeter per year
COD	-- chemical oxygen demand
DTPA	-- Diethylene Triamine Penta Acetic Acid
EC	-- electrical conductivity
g	-- gram
ha.	-- hectare
ha.-cm.	-- hectare-centimeter
JTU	-- Jackson Turbidity Units
kg	-- kilogram
kg/ha.	-- kilogram per hectare
km	-- kilometer
m	-- meter
meq	-- milliequivalent
mg/l	-- milligrams per liter
ml/min	-- milliliter per minute
mmhos/cm	-- millimhos per centimeter
MT/ha.	-- metric ton per hectare
MT/ha./yr	-- metric ton per hectare per year
No.	-- number
ppm	-- parts per million
r	-- correlation coefficient
R ²	-- coefficient of multiple regression squared
SS	-- suspended solids
TS	-- total solids
VS	-- volatile solids

SYMBOLS

C	-- carbon
Ca	-- calcium
CH ₄	-- methane gas

Cl	-- chloride
CO ₂	-- carbon dioxide gas
CO ₂ - C	-- carbon dioxide - carbon
Cu	-- copper
Fe	-- iron
H ₂ O	-- water
K	-- potassium
K ⁺	-- potassium monovalent cation
Mg	-- magnesium
Mn	-- manganese
N	-- nitrogen
N ₂	-- nitrogen gas
N ₂ O	-- nitrous oxide gas
Na	-- sodium
Na ⁺	-- sodium monovalent cation
NH ₃ -N	-- ammonia-nitrogen
NH ₄ ⁺	-- ammonium monovalent cation
NH ₄ ⁺ -N	-- ammonium-nitrogen
NO ₂ ⁻ -N	-- nitrite-nitrogen
NO ₃ ⁻ -N	-- nitrate-nitrogen
O ₂	-- oxygen gas
pH	-- the negative logarithm of the concentration of the hydrogen ion in gram atoms per liter
P	-- phosphorus
S	-- sulfur
Zn	-- zinc
°C	-- degree centigrade
#	-- number
%	-- percent